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Floristics and soil characteristics of the Warm Springs Seasonal Wetland, California

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FLORISTICS AND SOIL CHARACTERISTICS OF THE WARM SPRINGS SEASONAL WETLAND, CALIFORNIA

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ABSTRACT

FLORISTICS AND SOIL CHARACTERISTICS OF THE WARM SPRINGS SEASONAL WETLAND, CALIFORNIA

by Susan Rae Macias

Ecological studies of the Warm Springs Seasonal Wetland in Alameda County, California, were conducted to determine characteristics of the plant community structure and soils characteristics of vernal pools and saline seasonal wetlands on this site. The fresh water and saline vegetation communities, soils, and seasonal flooding characteristics were surveyed. Vegetation types and gradients were investigated using PCA analysis and nine vegetation types were determined. Two vegetation gradients were also identified. Vegetation types separated along two gradients: surface soil salinity and patterns of seasonal flooding. Soils in the wetland were either floodplain clays in vernal pools and seasonally ponded saline swales, or clays with an organic upper horizon in grasslands and some of the saline transitional floras. Surface soil salinities were variable, but significantly more saline in subsoils than in surface soils, and were more saline n unvegetated and continuously eroding in the lower floodbasins and in the upland grasslands.

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INTRODUCTION 3/04A DRAFT

Prior to the American expansion into California in the 1800s, the San Francisco Bay area had an extensive non -tidal seasonal fresh water habitat surrounding the southern reach of the bay. There were some 90,000 acres of grassland, vernal pool wetlands, willow swamps and riparian forests in south bay seasonal non-tidal wetlands and riparian corridors. Historically, approximately 24,000 acres of this wetland habitat was grassland and vernal pool complexes, of which 15,000 acres remain today (Goals Project 1999). In the vicinity of the San Francisco estuary, vernal pools were found on abandoned river terraces of drainages emptying into San Pablo and Suisun Bay tidal marshes, and on interfluvial flood basins and plains on the low, level margins of alluvial fans in the southern reach of San Francisco Bay (Figure 1).

The disjunct distributions of modern relict vernal pool floras in the south bay suggest that pool complexes occurred historically in moist grassland habitats in low lying areas. Relict floras today occur along the lower reach of the Guadalupe River in Santa Clara County, and on the low, flat margins of the Alameda Creek alluvial fan in Alameda County (Figure 2).

Presently, few examples of these wetlands remain in the southern San Francisco Bay. Most were lost to agriculture and ranching beginning in the mid seventeenth century, and more recently to rapid, extensive urbanization.

The largest vernal pool remnant in the south bay is the Warm Springs Seasonal Wetland on the Don Edwards San Francisco Bay Wildlife Refuge in Fremont, Alameda County. Warm Springs consists of 275 acres of saline and fresh water seasonal wetlands, including moist grasslands, alkaline grasslands, several intact mound and swale vernal pool complexes, and abandoned fresh water seasonal duck ponds. Portions of the historic saline basin rim and its ecotone with the upper floodplain are also preserved on this site.

The San Francisco Bay National Wildlife Refuge acquired the Warm Springs Seasonal wetland in 1992, but neither its floristics nor habitat characteristics have been extensively studied. The site has a number of rare and endangered species, notably *Lasthenia conjugens* (Contra Costa Goldfields), *Atriplex depressa* (Brittlebush), *Lepidurus pachardii* (Vernal Pool Tadpole Shrimp), and *Ambystoma californiense* (California Tiger Salamander) all of which are associated with vernal pool habitats.

Floristics and habitat characteristics are not well known here and a better understanding of the wetland habitats for both ongoing wildlife management, restoration and conservation efforts at Warm Springs and on adjacent mitigation sites, are needed.

This study investigates the historical distribution and geomorphological context of these seasonal wetlands as a whole, the basic soil characteristics relative to the floras common to these habitats, and their floristic composition and gradient patterns.

Before these rare and fragmented wetland remnants can be effectively interperated, they must have had an historical and ecological context amid the urban development that now surrounds them. It was necessary to briefly examine the few remaining seasonal wetland floras in southern San Francisco Bay area to determne where these wetlands might have actually been found historically. To do this, the locations of the few relict sites still in existence in 1996 were correlated with soil, geomorphological, and hydrological characteristics on historical maps of the south bay. This was done to outline what remains of the present distribution, and to reconstruct the possible historical extent of the distribution of seasonal wetlands around southern San Francisco Bay. The relict sites were then classified using a cluster analysis to compare the general relatedness between their extant floras.

The Warm Springs Seasonal Wetland in Fremont was chosen for more detailed ecological studies because it was the largest of the remaining sites. It also had the highest species richness floristically and was the least disturbed of the relict sites still in existence in 1998. Ecological studies in the Warm Springs wetland examined two basic components of the habitat: the soils, and the floristics. Both the saline and fresh water seasonal wetland habitats were included in this study. The flora was first characterized into six floristics associations or vegetation types using a two-component Importance Value as a quantitative description of each vegetation type. These six vegetation types became the vegetation units for both mapping the site and modeling the coenoclines or vegetation gradients of the wetland using Principle Component Analysis (PCA). PCA also provided a means of identifying some of the dominant environmental factors in the wetland habitat.

The soil salinity pH, and profile structure was studied spatially as they related to the plant communities in the wetland. Soil studies included characterizing the zonation within the soil profiles of the six vegetation types, and the salt distribution within the soil profiles. Soil characteristics were then used to explain some of the distinctive floristic associations in the Warm Springs flora.

Finally, the historic wetland site was tentatively reconstructed historically using the floristics, vegetation characteristics, geomorphology and soil characteristics of the Warm Springs site.

LITERATURE REVIEW

Historical Background

There is very little historical information available about the community composition and distribution of seasonal wetlands around the southern reach of San Francisco Bay. Cooper (1926) described this habitat as a continuous zone that occurred just above and adjacent to the extensive tidal salt marshes of the south bay. This zone ranged in elevation from sea level to approximately 25 feet on the lower margins of alluvial fans that surround and partially underlie San Francisco Bay (Figure 3).

Cooper's seasonal wetland zone corresponds geologically to a complex of interfluvial flood basins and marginal floodplains that encircle the bay from just north of San Francisquito Creek in southern San Mateo County on the west side of the bay, to the Milpitas floodplain at the southern end of the estuary. The floodplain then continues north on the eastern shore to San Leandro Bay in Alameda County (Helly and Lajoie. 1979).

The fine textured soils of the floodplain were deposited from standing floodwaters, which seasonally inundated the floodplains and basin during episodes of high stream flow. In addition to channeled flooding, fresh water was supplied to the low-lying floodplains as slopewash, sheetwash, and in shifting intermittent alluvial channels.

Creeks did not empty into the bay via discrete channels, but spread or fanned out onto the broad marginal floodplains before draining into the bay (Grosinger 2001).

Cooper (1926) witnessed a flooding episode of San Francisquito Creek near its mouth and described it as " a flowing broad muddy sheet over the surrounding fields, leaving behind large quantities of sand and silt as it went. It spread over the salt marsh where there was no semblance of a definite channel, and finally reached the bay".

The first European explorers of San Francisco Bay and the Santa Clara Valley also referred to the character of this habitat during the rainy season. Gaspar de Portola, in November of 1769, described the floodplains of San Francisquito Creek near the present day Palo Alto as "thickly grown over with oak trees, and having many lagoons and swamps" (Truethein 1968). George Vancouver wrote of a trip on horseback to the Santa Clara Mission, across the the Guadalupe River floodplains in the winter of 1794; " We arrived in a low, swampy country through which our progress was slow, the horses being knee deep in water for about six miles. The badness of the road rendered this part of our journey somewhat unpleasant" (Vancouver 1801).

Father Pilou of Rivera's expedition of 1774 noted that the floodplain was " one of very level land and well covered in pasturage, but lacking in firewood, for there is no timber other than along the river…" (Truethein 1968).

In the delta at about the 100-year flood line on the old abandoned terraces of the San Joaquin River, the riparian forest graded into valley oak savanna, and broad reaches of perennial grasslands dotted with vernal pools (Harvey et.al.1992). The non-saline seasonal wetlands above the tidal marshes of San Francisco Bay were also apparently, in part, vernal pool grasslands such as this, transitioining at higher elevations into oak forest and savanna, and at lower elevations, into saline seasonal wetlands.

Today, most of the extant fresh water seasonal wetlands are palustrine or "farmed" wetlands and pasturelands. Hay and grain crops such as wheat, oats and are commonly cultivated in the North Bay. Livestock grazing is typical of the lowest flood prone basins and swales. Cooper (1926) noted that the fresh water seasonal wetland zone on the Palo Alto alluvial fan was " almost entirely given over to wheat raising" by 1915. A few remaining flood prone areas in Alviso in Santa Clara County are still used primarily as pastureland, though most of these areas are being rapidly lost to development. The Warm Springs wetland in Alameda County was used primarily as pastureland, up until 1991.

When Cooper (1926) documented the natural floras of fresh water seasonal wetlands, he briefly described the low wetland zone as a "willow- composite community", dominated in the wettest areas by thickets of *Salix lasiolepis* (Arroyo Willow), with an associated community of composite species including *Hemizonia luzlufolia* (Tarweed), *Hemizoinia pungens, Aster chilensis, Aster exilis, Baccharis douglasi* (Coyote Bush), *Iva exillaris*, and *Solidago occidentalis* (Goldenrod). Wheat fields on low floodplains, Cooper noted, were subject to invasions of *Hemizonia,* which was not very common until the wetlands until they were cultivated. This suggests that *Hemizonia* was likely a disturbance invasive in the local flood basin floras in the 1920s.

Where the water table was perched or nearly so at the surface, stands of *Salix lasiolepis* formed dense and often extensive thickets 30 ft. high. Remnants of one such willow swamp still exists in Coyote Hills Regional Park in Alameda County, but Cooper willow swamp still exists in Coyote Hills Regional Park in Alameda County, but Cooper noted that most of them were cut and cleared as the lowlands went into cultivation in the 1800s.

Historically, floras on seasonal floodplains in the south bay were predominantly perennial and alkaline grasslands in which vernal pool complexes and willow thickets occurred. Historic perennial grasslands were dominated by *Leymus multiflorus* (Wild Rye), associated with *Carex boraceae* (Sedge), *C. paergracilis, Nasella pulchra* (Purple Needle Grass), *and Leymus. Triticoides* (Creeping Wild Rye) in topographic depressions. *Juncus balticus* (Baltic Rush), *J. xiphoides, Ranunculus californicus* (California Buttercup), and *Sisyrhinchium bellum* (Blue-eyed Grass) occurred in the wetter moisture sinks and depressional seasonal grasslands. Alkaline grasslands were common in the grassland-tidal marsh ecotones. *Distichlis spicata* (Salt grass) was a dominant species forming dense seasonally - flooded meadows. Common subdominant species included *Hemizonia congesta* and *Hemizonia. pungens.*

Non-native annual grassland communities, introduced with the onset of cattle ranching and agriculture in the 1800s, have supplanted most of the historic native perennial grassland floras. *Lolium* (Wild Rye)-*Bromus* (Brome)-*Hordeum* (Foxtail)-*Avena* (Wild Oats) complexes have replaced the once widespread *Leymus-triticoides-Nasella pulchra* pereninial grasslands on local clay floodplain soils that are characteristic of local annual grassland communities. Common weedy forbs that accompany grasses in modern annual communities include *Picris echoides* (Prickly Lettuce) and *Centauria solstitalis* (Yellow Star Thistle) (Holestein 2000).

Dispersed within the grasslands on south bay floodplains were vernal pool complexes. They occurred within seasonally flooded grassland habitats. Vernal pools throughout California have distinctive and unique floras consisting of many species found primarily in the genera *Downingia* (Cailico flower), *Eryngium* (Button Celery), *Navarretia, Psilocarphus* (Wooly Marbles) *and Plagiobothrys* (Popcorn Flower). Species diversity is high in these communities and varies as a result of geographic adaptive radiation between pool complexes distributed throughout California, seasonal wetlands on historic flood basins and plains of the alluvial fans were typically both fresh and variably saline alkaline grasslands were common. (Holland and Jain 1977, Holestein 2000) The saline component was, in part, ecotonal and tended to occur on lower floodbasin rims. Saline seasonal wetlands transitioned into the tidal salt marshes at lower elevations, and into the non-saline grasslands above (Helley and Lajoie 1979). Most of the historic south bay flood basins and plains had this soil salinity pattern.

Cooper (1926) described these saline basin rim zones as irregularly flooded and variably saline, since they were flooded seasonally from both the estuary below and from the alluvial fan above. Historically, flooding from the estuary was seasonal and unpredictable, and would have been most pronounced when the higher high tides coincided with periodic storm events, which amplified them into winter "storm tides".

In the south bay seasonal wetlands, the lower saline basin rims were often dominated by *Salicornia virginica* (Perennial Pickleweed) in swales and depressions. Historically, these saline floras gave way to those of the willow-composite seasonal wetlands and moist grasslands on the upper floodplains where fresh water flooding dominated the hydrology (Cooper 1926, Holestein 2000).

There were four possble sources of seasonal flood waters on the historic interfluvial basins and floodplains of the south bay; (1) seasonal fresh water flooding from majior distributaries draining the alluvial fans, (2) fresh water surface runoff as overland flow from the upper fan, (3) seasonal flooding from the tidal basin of the adjacent estuary, and (4) seasonally elevated ground water tables on the lower floodplains (Helley and Lajoie 1979).

Cooper (1926) found that the distribution of fresh water seasonal wetlands coincided with the occurrence of the ground water table at or near the surface on the Palo Alto alluvial fan. A shallow, saline aquifer underlies the southern Alameda Creek alluvial fan, creating some of the saline soils of the floodplains in Alameda County (Davies 1966, Helley and Lajoie 1979).

Environmental Factors in Seasonal Wetland Habitats

Soils on floodplains of river terrace complexes and alluvial fans are generally poorly draining fine textured loams, clay loams, sandy clay loams or clays (Keeler 1995). Claypans often develop on older, intensely weathered river terrace and elevated coastal marine terrace soils on which vernal pools typically occur in California. Water movement through such agrillic soils decreases with depth as the clay content of the soil subhorizon increases. Vertical drainage through agrillic soil drops to near zero when the clay content approaches 40 %. Floodplain soils, because of their high clay content, tend to readily pond water, and to lose it through evapotranspiration rather than through vertical infiltration (Zedler 1987).

Unlike the old weathered soils of marine and river terraces where vernal pool wetlands commonly occur in California, south bay seasonal wetland soils are young geologically. They range in age from recent to about 5,000-7,000 years old. They include clays of the Alviso, Clear Lake and Pescadero soil series, and clay loams of the Marvin and Omni soil series (Welch 1980, Wier and Storie 1947).

There are two distinct clay soil types in south bay floodbasin deposits. One is a fine textured salt affected clay found on low basin rims. It is typically seasonally saturated at the surface with saline groundwater from the adjacent estuary and salt pond complexes. The other soil type is an upper floodbasin clay similar to the basin rim clay in composition, but is not saline (Helley and LaJoie 1979).

Studies of soil characteristics in seasonal fresh water and brackish wetlands in Suisun Bay had a characteristic vertically stratified salt distribution. Salt concentrations were typically lower in the first 30 cm, of the measured soil profile, and higher but more stable in the lower 60-90 cm, subhorizons (Mall 1969).

Seasonal fresh water flooding of previously dry, saline wetland basins significantly reduced surface salt concentrations, as salts were leached out of the surface soils and translocated down into the subsoil horizons by the ponded fresh water. Surface soil salinities increased, however, as soil moisture decreased in drying soils during the summer drought (Rollins 1981).

Vertical salt concentrations in soil profiles on interfluvial flood basins adjacent to tidal marshes near Alviso in Santa Clara County were stratified in a manner similar to seasonal wetlands in Suisun Bay. In saline basin rim soils on the Guadalupe River flood basins, surface soil salinities ranged from 2 to 8 ppt, while subsurface salinities at one meter of depth ranged from 2 to 20 ppt (Gardner et.al. 1958).

Rollins (1981) found that the two most significant environmental factors affecting plant species composition and distribution in Suisun Bay seasonal marshes and duck ponds, were soil salinity and the depth and length of time of submergence during seasonal flooding. The length of time of submergence was a major contributing factor of vegetation zonation in seasonal wetlands, as well, though not as pronounced as in tidally flushed marshes. Prolonged submergence also delayed germination and spring growth of some wetland plant species in the middle and upper elevations of both seasonal and tidal wetlands.

In vernal pool habitats on southern California elevated marine terraces, Zedler (1987) found that species distribution within vernal pool basins was partly determined by the depth of seasonal standing water, and more significantly by the length of time of submergence.

Because the soils of wetland soils tend to have high concentrations of organic material, they tend to be moderately acidic to neutral at lower salinities. Organic compounds decompose into humic, fulvic and various other carboxylic acids in wetland soils, which tend to render them mildly acidic (Lytersen 1998). On irregularly flooded tidal marsh soils in the Gulf States, soil pH decreases with increasing organic content.

Odem et.al. (1983). found that salt marsh pH ranged between 6.0 and 6.5 in East Coast wetlands. In Suisun Bay seasonal wetlands, Rollins (1981) found that soils with a high organic content, even though often saline, were strongly acid.

Soil pH in fresh water vernal pools tends to be mildly acidic to neutral, ranging in pH from 6.0-7.0, since vernal pool basins often accumulate a great deal of organic matter (Environmental Labs 1978). Neutral to acid vernal pools on the Santa Rosa Plateau in southern Cailifornia occur in permeable to semi-permeable basins, but closed basins with poor drainage are often alkaline. They are essentially small evaporate basins in which salts accumulate from local runoff during repeated cycles of flooding and drying (Zedler 1987).

Soil pH often increases in conjunction with salt-water intrusions, as seawater pH typically ranges from 7.5-8.3, (Harvey1969). Ground water and rainwater runoff containing Mg and Ca bicarbonates are often moderately alkaline. Surface and ground water in both Santa Clara and Alameda counties are of this type, with pH ranges of 8.0-8.3 (Warner 1970).

The San Francisco Bay area has a Mediterranean climate, characterized by warm, dry summers and mild, wet winters. Rainfall in Mediterranean climates ranges between 25-100 cm (10-40") annually, and is highly variable from year to year (Dallman 1998).

Vegetation cover in Mediterranean climate regions tends to be incomplete, with much bare ground due to summer water stress. Grasslands dominate plant communities locally where annual rainfall ranges from 25-51 cm (10-20") and decreases where it exceeds 51 cm. In the bay area, grasslands dominate plant communities on locally abundant heavy clay soils, which retain surface moisture well into the drought season (Holestein 2000).

Vernal pool wetlands occur almost exclusively in Mediterranean climates on impermeable or poorly draining soils (Zedler 1987), and locally only on alluvial clay floodplains (Holestein 2000).

Closure of saline tidal wetlands to tidal circulation by diking or diversion often creates saline seasonal wetlands. They approximate naturally occurring saline seasonal wetlands since they often become dry during the summer drought as a result of loss of, or diminished tidal circulation. Such habitats have broader seasonal soil moisture and salinity ranges than do tidal wetlands. Sensitive species of the lower tidal marshes tend to drop out of such habitats, and do not occur at all in natural saline seasonal wetlands.

Southern California tidal marshes with unpredictable or irregular flooding support monotypic stands of *Salicornia virginica*. Both *Salicornia virginica* and *Frankenia salina* (Alkali Heath) dominated similar wetlands with intermittent tidal flushing inlagoons along Los Penaquitos Creek in southern California.

Zedler (1987) found that plants with well-developed root systems, such as perennial halophytes, survived the drought periods better than shallow rooted annuals, which typically have poorly developed root systems. Mature, long-lived species may also track declining groundwater tables in the dry summer season better than short-lived, shallow rooted annuals in seasonal wetlands.

Vernal pool plant species often show soil salinity preferences in variably saline habitats. *Cordylanthus palmatus*, the rare Palmate - bract Bird's Beak of the Springtown

Alkali Sink near Livermore, California, was most abundant on soils of intermediate salinities, was scarce at high soil salinities, and was absent altogether in non-saline upland soils (Coats 1988).

There were distinct seasonal successions in mixed halophyte and fresh water seasonal wetland floras. At Springtown, the vernal pool species *Downingia pulchella, D. cuspidata*, and Lastheniia sp. dominate the spring flora in drying pools. The summer flora on the dry basins, however, consists of *Atriplex patula* (Fathen), *Distichlis spicata*, and *Allenrolfia cccidentalis* (Pickleweed), all halophytes (Coats 1988).

In marshes where soil salinities vary from fresh to saline, soil salinity tended to control the vegetation zonation patterns (Mitsch 1986). When soil salinites in saline marshes decreased to about 5 ppt, salt marsh vegetation was replaced by brackish or fresh water species. In Suisun Bay seasonal wetlands, Mall (1969) found that plant species composition was determined by the soil salinity during seasonal flooding. *Salicornia virginica* was dominant at salinities of 35 ppt or more, *Cotula coronopifolia* (Brass Buttons) between 30.5-90 ppt and *Distichlis spicata* between 11.6-43.5 ppt. All species typically required reduced soil salinities for seed germination and seedling survival, but mature plants were tolerant of higher soil salinities.

SITE HISTORY AND DESCRIPTION

Relict Sites

In 1996, there were still a number of seasonal wetland sites scattered around undeveloped areas in Alviso, in Santa Clara County, and in the Fremont and Newark area development, and no longer exist. Species lists were the only data compiled for the sites (Appendix 2).

There were four such sites in the Alviso area in 1996 The most extensive site was near Disk Drive in Alviso, and consisted of seasonally flooded depressional wetlands and vernal pools on a fallow agricultural site (Figure 2,A). Several vernal pool indicators occurred in the flora there, notably *Downingia pulchella* (Flat-faced Calico Flower), *Limocella aculis* (Mudwort) and *Eleocharis macrostachya* (Spikerush). The vernal pool fairy shrimp, *Bracyhnecta lindhalli* and a venral pool pulmonate snail *Limnaea sp.* were also common in the flooded pools in the early spring. The site has since been graded and paved as a parking lot. Along Los Esteros Road in Alviso is another relict site on the old Arzino's Ranchlands with a flora similar to that of Disk Drive. This area consists of both fallow farmland and grazing pastures on an old floodbasin of the Guadalupe River. The Yerba Buena Road site near the 237 freeway was also an abandoned field. Several vernal pools and frog ponds were found on this site.

Vernal pool fairy shrimp were especially common in these pools .The site been developed as an industrial park. On the Great America Parkway nearby, were several more pools in an abandoned field. These were primarily frog ponds in the spring, but fairy shrimp and several species of vernal pool plants were found in the pools as well. It has also been developed as an industrial park.

In Alameda County there are two sites. One is in the Coyote Hills Regional Park, on seasonally flooded, fallow agricultural land. This site has a vernal pool flora similar to that of the old Disk Drive site in Alviso, and is presently managed as seasonal wetland.

The most extensive of these remnant sites is the Warm springs Seasonal Wetland in Fremont. This site, because it was the largest and best preserved of the relict sites, was chosen for the more extensive plant and soil studies and is described in detail in the next section.

The Warm Springs site

Warm Springs Seasonal Wetland is located on the southwestern margin of the Alameda Creek alluvial fan in Fremont, Alameda Co., Ca. (Figure 4A). The site consists of 275 acres saline and fresh water seasonal wetlands and grassland habitat, (Albertson pers.com.1998).

The Ohlone Indians lived in this area prior to Spanish expansion into California in the late seventeenth century. During the Mission Period, the site was included in the Mission San Jose land grant of 1787 (Holmes 1997). In 1879, Warm Springs was owned by J.R. Spring, as ranch land (Thompson and West 1879). In 1892 the site was purchased by Samuel and Margaret Poorman, who sold the parcel in 1896 to G. F Bowman for 25,000 dollars (Alameda Co. Deed records 1893). In the 1920s through the 1930s the land was owned by Joe Eastwood, who built the duck ponds in the northern sector of the site. Duck clubs and cattle grazing were the only documented land use on the site at this time. From the 1940s through the 1960s, dairy cattle were grazed on the site. In the 1970s Hereford and Angus beef cattle were grazed there year-round (Reynolds, pers comm. 2003). Warm Springs has led a precarious existence in more modern times. In the 1970s, the city of Fremont slated the site for a proposed housing development that never came to pass. In 1983 it was included in an industrial redevelopment plan that was never implemented. In

1985, it was the site of a proposed airport, which was never constructed. In 1990, the development company which then owned the site went bankrupt, and it was aquired by Sanwa Bank, which eventually sold the parcel to the Fish and Wildlife Service in 1991, as a seasonal wetland preserve. On 25 April 1992, the site was dedicated as part of The Don Edwards San Francisco Bay National Wildlife Refuge. Shortly after the acquisition, breeding California Tiger Salamanders and Vernal Pool Tadpole Shrimp were discovered on the site, (Olsen, 2001).

Warm Springs Seasonal Wetland is part of the Alameda Creek alluvial fan. The fan is a network of active and inactive natural stream levees and their associated floodbasins (Lajoie, unpub.data, 2003b). The Warm Springs site, located on the southern portion of the fan, is, in fact, an abandoned or inactive stream levee and floodbasin complex (Figure 5). The abandoned stream levee bisects the site as an elongated and gently elevated, upland grassland. Adjacent to the levee, on either side are two abandoned floodbasins. In each of the floodbasins, there are two distinct edaphic zones. The upper reaches of the basins are non-saline, and are primarily a mound and swale topography in which fresh water vernal pool complexes are found scattered throughout the grassy swales. Also on the upper floodbasin, in the slope transitions between the old stream levee and the upper floodbasin floor, there are several distinctive erosional zones, which were too limited in area to be quantitatively surveyed in the vegetation study. They are characterized by sparsely vegetated saline-alkaline erosional slopes, which drain into saline-alkaline vernal pools. The slope flora is dominated by *Sueda moquinii* (Alkali Seepweed) and pools. The slope flora is dominated by *Sueda moquinii* (Alkali Seepweed) and *Hemizonia pungens*, the pool flora by *Atriplex depressa* (Brittlebush), *Sueda moquinii*, *Lasthenia conjugens* and *Plagiobothrys stipitatus*.

The lower basin soil salinities vary considerably. In these saline areas, large portions of the surface soils in what once was a mound and swale terrain have been removed by surface water erosion and historic flooding from adjacent drainage canals confluent with Mud Slough at the south end of the site. The extensive erosion has left behind a confused landscape of remnant grassland mounds, irregularly vegetated hummocks and swales, and broad expanses of unvegetated saline drainage slopes, salt flats and hypersaline swales. The grass-covered mounds scattered throughout the lower portion of the western basin are remnants of a mound and swale topography that was originally similar to that of the upper basin. In a narrow, irregular zone separating the saline lower basin from the upper basin is a variably saline transition zone. This zone also occurs on the slope transitions between the stream levee and the basin floor on both sides of the levee in the lower floodbasin.

The floodbasins and adjacent habitats have been extensively altered since the 1800s. Much of the area of the lower floodbasins, their ecotonal boundaries with historic tidal marshes, and the tidal marshes themselves, were converted to salt evaporators in the 1950s (USGS 1953). Prior to conversion, portions of the lower floodbasins were dotted with duck ponds and duck blinds, and a duck club, traces of which can still be seen in the drained A22 salt pond along the southern boundary of the site. Presently, this hypersaline low floodplain area is a dry salt pond and managed as Snowy Plover *(Charadrius* now abandoned. The northern sector of the site is fallow farmland, and probably a portion of another abandoned stream levee. It consists of upland grassland and some wetland grassland habitat. A flood control canal, constructed in the 1980s, interrupts the historic surface drainage of the floodplain, and much of the abandoned stream levee was channelized with a series of short, parallel trenches to drain low areas of pastureland on the stream levee between the fresh water vernal pool complexes. This trenching probably initiated the erosion that created the unusual saline-alkaline vernal pool habitats on the slopes of the abandoned stream levee. Historic natural drainage is further interrupted by numerous salt pond levees, small duck pond berms, access roads, and drainage canals on and surrounding the site. The Warm Springs floodplain is relatively low- lying terrain, with a total topographical relief of approximately 5 feet (1.52 m). The highest site elevation is 10 feet (3.04 m) above sea level on the inactive stream levee, and the lowest points occur along the perimeter salt pond levees at 5-ft. (1.52 m) of elevation in the lower floodbasins. Large portions of the wetland flood seasonally in the floodbasins, primarily in the saline lower basins, abandoned duck ponds, and in the depressional areas of the vernal pool mound and swale zones in the upper basins. The seasonal extent of flooding is variable from year to year (Figure 6). The region is subject to a good deal of annual variation in total rainfall. Rainfall in San Jose (which is similar to that of Fremont) averages 15 inches (38.1 cm) a year, most of which falls between October and May (San Jose Weather Station 1998)

MATERIALS AND METHODS

Geographical Data

Geographical locations of 6 relict sites surveyed in 1996, including the Warm Springs site (Figure 3), were plotted on a base map of floodplain and flood basin distribution of southern San Francisco Bay, adapted from Helley and LaJoie (1979) and Goals Project (1999). Sites were surveyed for species composition and the degree of similarity between respective relict floras was calculated using a Jaccard's presence/ absence similarity index (JSI). A cluster analysis was then performed using the JSI site indices to compare both site similarity and the historical geographical distribution of vernal pool species in the site floras. The results were then plotted as a standard linkage diagram where a JSI index of 50 or greater represents the same floristic association, 100 equals identity, and zero equals complete difference (Barbour et.al. 1987).

Quantitative Plot Surveys

Quantitative surveys of the flora on the Warm Springs site were conducted in June 1998 at the peak of the spring bloom of the annual plant species in the floras. The Warm Springs flora was divided into six stratifications or vegetation types based initially on general species composition These VTs were designated as follows:

1. Exotic upland grassland
2. Higher elevation wetland transition zone
3. Lower elevation transition zone
4. Pickleweed swale
5. Abandoned fresh water (upland) duck ponds

6.Fresh water vernal pools

Each vegetation type was quantitatively sampled using a stratified randomized design (Southland 1996). Three plots, 15 x 30 m (Figure 7), were selected at random within each VT, and ten 30 x 30 cm quadrats were randomly selected within each plot. Biological factors measured within each quadrat included species composition, abundance per species and percent cover for each species. The minimum number of quadrats required per plot was determined using the successive means method (Barbour et.al. 1987, Greg-Smith 1983).

Soil Salinity

Surface soil samples were collected with a standard auger soil sampler. Vernal pools and duck ponds known to harbor endangered Lepidurus *packhardii* and Lasthenia *conjugens* were not sampled so as not to impact "egg banks" of the tadpole shrimp or the seed banks of *Lasthenia conjugens*, which are found in the dry pool basins.

Apparent Soil salinities were determined by the method of Powell (1994), which yields a soil salinity index with a value that underestimates the absolute value. Twenty grams of dry, pulverized soil were added to 100 ml of glass-distilled water and stirred for one hour to dissolve soil salts into suspension. The suspension was then allowed to settle until the liquid was clear. The liquid was then decanted and filtered. The salinity of the water extract was then measured at a standard temperature of 25 degrees C with a YSI model 33 S-C-T salinity meter.

Spatial Survey Mapping

A preliminary base map was prepared of the Warm Springs site from a black and white aerial photograph, which was then used to prepare a tentative map of vegetation distribution of the site. The preliminary map was then ground truthed using the transect method of Zonneveld (1988) and Kuchler (1988). A compass and GPS receiver provided ground control. The six VTs characterized in the previous plot surveys served as the principal vegetation map units. These mapping surveys were carried out in May of 1999, during the peak of the spring bloom that year.

Vegetaton Characterization

Importance value index per species within each vegetation type. Importance value is the sum of the relative values (%) of abundance relative percent cover, and relative frequency per species. Importance value is thus a measure of the relative contribution of each species to a community or association, expressed as a value between 1 and 300 (Barbour et.al. 1987). These were then summarized in a table for each species in each vegetation type.

Soil Gradient Maps

Surface soil gradients were measured and mapped from 52 soil samples collected along transects covering the entire Warm Springs site, using a compass and GPS receiver to provide ground control. Surface soil samples were collected in July of 2000, with a standard auger sampler, when the suffₐce soil was dry. Both surface soil samples and soil samples at one meter of depth were also collected in February of 2001 during the rainy season. These data were used to map soil salinity spatial gradients during both the summer drought and the rainy season. Soil pH was mapped during the rainy season only.

Soil Profile salinity and pH

Soil pH was measured with a Hellige-Truog soil reaction test kit. This method was chosen because it required but a small sample of soil to perform..

Forty core samples collected for spatial gradient analysis were pooled and the salinity and pH of surface and subsoils were compared for soils on the entire site. An unpaired sample t test was used to test the significance of differences between surface and subsoils at one meter of depth for both apparent soil salinity and pH.

Random soil core samples were also collected from each of the edaphic zones, nine each from the upper vegetated floodpain, the lower vegetated floodplain, and unvegetated zones of both the upper and lower floodplain. Their salinities were also compared using unpaired sample t test for differences in surface soil salinites between edaphic zones, and differences in soil salinities between the surface soil and the subsoil at one meter of depth within the three edaphic groups.

Vegetation Gradient Analysis

Principal Component Analysis (PCA) was used to summarize the vegetation gradient from the species composition and abundance site data collected in 1998. The resulting PCA analysis was then used to identify dominant environmental factors responsible for producing the vegetation patterns, as well as to model the vegetation gradient. PCA is often used to summarize plant community patterns, and as a means of identifying environmental factors indirectly from the plant community data when direct environmental data is unavailable (Gauch 1999). The assumptions are that: (1) community gradients summarized in the ordination should relate to environmental gradients, (2) patterns of plant species distributions and abundances are indirect measures of environmental factors or factor complexes that produced them, and, (3) environmental gradients are often dominated by only a few major environmental factors which will be identified from the data set in the PCA analysis. Each principle component represents one or more of these environmental factors, expressed indirectly as a vegetation pattern or gradient.

However, the actual identification of environmental factors from plant community data is somewhat subjective. It does require some prior knowledge of environmental factors that known to be important in the habitat in question or in similar habitats to the one under investigation.

Since two potentially important environmental factors, soil salinity and flood magnitude (depth and duration of flooding) could not be measured due to permit restrictions, PCA was chosen as an alternate method of identifying the principle environmental gradients in the plant community.

A subset of four species variables measured as species abundances were used for the PCA analysis of the eight plots in the survey. Variables were omitted which were too highly correlated in a Pearsons Product Moment Correlation Coefficient Analysis ($r = 0.60$ or greater). The number of variables permissible in the PCA was also limited by sample size, with one variable allowed per each five observations, permitting three variables in the PCA analysis (McGrigal et.al. 2000). The variables retained were *Lolium* *multiflorum* abundance as a grassland indicator, *Salicornia virginica* as a saline wetland indicator and *Plagiobothrys stipitatus abundance*, and *Downingia pulchella* abundance as fresh water wetland or vernal pool indicators. Two PCA vegetation gradient models were thus possible, One combining *Lolium*, *Salicornia* and *Plagiobothrys*, and one substitution, *Downingia* for *Plagiobothrys*.

PCA was used here to reduce a 3-variable data set per plot to a single factor score per plot. The factor score was used here as a floristic similarity index per plot, which could then be used to graphically compare the floras of each of the plots using three indicator species simultaneously as a measure of similarity between plots. This is a simple means of plotting the dominant vegetation gradient patterns from the floristic plot data. The pattern of gradient variability between the six vegetation types and the factor loadings of the three indicator species were then used to possibly identify the dominant environmental gradients that generated the vegetation gradients extracted by the PCA analysis. The Systat 8.0 statistical package was used for this analysis.

RESULTS

Vegetation

Geographical Distribution of Vegetation

All of the six remnant seasonal wetland sites in the 1996-97 surveys were found on old alluvial fan interfluvial basins and floodplains in Santa Clara and Alameda Counties (Figure 2). Remnant seasonal wetland sites were fresh water, habitats. Relict vernal pool annuals in low-lying depressions frequently dominated the floras and annual environmental gradients that generated the vegetation gradients extracted by the PCA analysis. The Systat 8.0 statistical package was used for this analysis.

RESULTS

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Geographical Distribution of Vegetation

All of the six remnant seasonal wetland sites in the 1996-97 surveys were found on old alluvial fan interfluvial basins and floodplains in Santa Clara and Alameda Counties (Figure 3). Remnant seasonal wetland sites were freshwater, habitats. Relict vernal pool annuals in low-lying depressions frequently dominated the floras and annual exotic grasslands surrounded them. Vernal species were both native and exotic, and often intermixed with salt marsh and alkali flat halophyte species. The most widespread of the vernal pool species were *Downingia pulchella, Eleocahris macrostachya, Lythrum hyssopifolia* (Loosestrife), and *L. tribracteatum* (Three-bract Loosestrife).

A Jaccard's Similarity Index (JSI), and cluster analysis of species composition data (Figure 8), showed a high degree of similarity (cc=50) among the less disturbed and attenuated floras. Coyote Hills (CH) in the east bay, and Disk Drive (DD) on the west shore of the bay in Alviso had the highest fidelity (cc=91) among survey sites. Of the six sites surveyed, Warm Springs Seasonal wetland in Fremont, Alameda Co. had the richest vernal pool flora. Site 3C near Alviso had the lowest richness. The clusters that were most similar to each other (cc=73) were small (less than an acre in size), fragmented sites that were historically farmed wetlands, followed by the 3C site frog ponds or vernal pools with poorly developed floras (cc= 73.9). The Warm Springs site, in contrast, was large (275 acres), and had been pastureland. Since the Warm Springs site preserves much of the original mound and swale topography of the historic vernal pool wetlands, it was probably less impacted by land use than the farmed wetlands were. Species composition of the six relict seasonal wetland sites is shown in Appendix 1.

Vegetation Characterization

An importance value index was used to characterize and quantitatively describe the Warm Springs flora. Six floristic associations or vegetation types were determined as follows:

Grassland (Table 1) was the dominant non-wetland flora at Warm Springs as well as being the portion of the floodplain in which vernal pool mound and swale complexes were found. Grasslands were dominated by *Lolium multiflorum* (Italian Ryegrass). Subdominants included *Hordium leporinum ssp murinum* (Foxtail), *Frankenia salina* (Alkalai Heath), and *Hemizonia sp.* Species richness in grasslands was low and soils were characteristically nonsaline (Table 1). Exotic annual grasses dominated grassland floras, but halophytes, particularly *Frankenia salina*, were common in this vegetation type.

Vernal pools (Table 1) were fresh water ephemeral habitats (Table 1). They had relatively high richness and relatively low Importance values per species. They were dominated by *Psilocarphus brevissimus*, and *Downingia pulchella* (Flat-faced Downingia), both native annuals. Subdominant vernal pool species included *Lythrum hyssopifoli*, *Plagioboyhrys stipitatus* (Stipitate Popcorn flower), and *Lasthenia conjugens* (Contra Costa Goldfields). Halophyte species included *Cotula coronopifolia*, *Frankenia* *salina, Distichlis spicata* (Salt grass), and *Salicornia virginica*. Vernal pool annuals dominated vernal pool floras but halophytes were also typically abundant. Grasses were absent altogether in vernal pool basins.

The upper duck ponds in the northwest portion of the site were fresh water seasonal wetlands (Table 1) created by impoundment of rainwater and rainwater runoff within a system of low, confining berms. They were dominated by the halophyte grass *Distichlis spicata*. *Frankeni. salina* was present but uncommon. Vernal pool species included *Downingia pulchella*, *Lythrum tribracteatum*, *Limosella acaulis*, and *Eleocharis macrostachya*.

Duck pond floras were similar to those of vernal pools, in that vernal pool annuals dominated them, with halophytes as codominants. Grasses were also absent in duck pond flora. The lower duck ponds in the southeastern area of the site were privately held in 1998 and were not included in the vegetation surveys.

Low elevation transition zones were found between low floodplain pickleweed swales and the upland grasslands (Table 1). They were a mix of exotic annual grasses, halophytes and vernal pool plants. The vernal pool species were present in these floras in areas where soil salinities within the transition zone were relatively low. Codominants were *Cotula coronopifolia* (Brass Buttons), and *P. stipitatus*. Subdominants Included *Lolium multiflorum*, *Hordeum murinum ssp multiflorum*, *Frankenia salina*, and *Myosurus minimus* (Mousetail).

Vernal pool plants dominated the lower salinity transition zone floras, but grasses were also characteristic of this zone where seasonal flooding was brief (Table 1).

Halophytes were an important component of these floras, often associated with the vernal pool species.

Higher elevation Transition zones did not pond water. *Juncus bufonius* (Toadrush) dominated the, higher elevation transition zones and served as an indicator species of this transiton zone since it occurred nowhere else in the wetland. Subdominant species included *Salicornia virginica, Lolium multiflorum,* and *Hordium depressum* (Table 1).

This higher salinity transition zone was dominated overall by halophytes but with a significant grassland component.

Pickleweed swales (Table1) were depressions that flooded during most of the winter rainy season. They were saline to subsaline habitats. *Salicornia virginica*, and the vernal pool annual *Limosella acaulis* dominated pickleweed swales. Subdominants included *C. coronopifolia, Frankenia salina*, and the vernal pool annual, *Plagiobothrys stipitatus*. Pickleweed swales were often dispersed between unvegetated, variably saline runoff slopes, swales and within the hummocky terrain of the transition zones. They were dominated by vernal pool species in lower salinity swales that received only rainwater runoff during flooding. Halophytes otherwise dominated pickleweed swales.

Environmental Gradients

The PCA analysis extracted two dominant vegetation gradient patterns or factors from the 1998 plot data. In the gradient model using *Plagiobothrys* (Figure 17), these two factors explained 94.44% of the variance in the data set. Factor 1 accounted for 59%, and factor 2 accounted for 35.4% of the total variance explained.

In the *Downingia* PCA gradient model (Figure 17), Factor 1 explained 55.5 % of the variance in the data set, and factor 2 explained 37.8 %, with a total variance explained of 93.3 %. In factor 1, the grass component (*Lolium*) was positively correlated with the saline wetland component (*Salicornia*), and negatively correlated with the fresh water wetland component (*Downingia*). Since both the grass component and the saline wetland component are salt tolerant (Baye 2000) and positively correlated, but negatively correlated with the fresh water wetland component, factor 1 was interpreted as a soil salinity gradient. Factor 2 had two components negatively correlated with one another, the grass (*Lolium)* and the saline wetland component (*Salicornia*). Since the grass component and the saline wetland component were negatively correlated, factor 2 was interpreted as a flood gradient.

The PCA results suggest that an environmental factor complex consisting of a soil salinity gradient and a flood magnitude gradient which primarily controlled the vegetation gradient on the Warm Springs floodplain.

The PCA clustered the vegetation plots into 9 distinct groups, seven of which were in wetland habitats, and one in the upland habitat (Table 5). Pickleweed swales were segregated into two groups: subsaline swales, which lacked vernal pool annuals, and saline swales in which they were present. Transition zones were clustered into three groups: higher elevation transition zones, in which grass abundance was high, lower elevation transition zones in which the grass abundance was diminishing, and low elevation subsaline transition zones in which grasses were absent and vernal pool annuals were present. Vernal pools were clustered into two groups, pools in which *Saliconia* was present, and pools in which it was absent. The ninth group was the upland grassland.

The PCA also characterized two vegetation gradients in the Warm Springs flora. One was a subsaline to non-saline wetland gradient in which subsaline pickleweed swales were replaced in turn by the subsaline transition zone and the vernal pool floras along a diminishing soil salinity gradient .The second was a high salinity vegetation gradient in which saline pickleweed swales and low grass transition zones replaced high grass transition zone along a diminishing flood gradient

Spatial Vegetation Distribution

In the vegetation distribution on the Warm Springs floodplain was mapped in 1999 (Figure 16), grassland and vernal pool floras dominated the upper floodplain in general, but were replaced by mixed grassland and ruderal floras at higher elevations. Vernal pool mound and swale zones in old floodbasins were confined to two low elevation grassland areas on either side of the abandoned stream levee. Above the duck ponds was another abandoned stream levee with a mixed flora of alkali grassland, dominated by *Distichlis* meadows, moist grasslands, annual exotic grassland and degraded vernal pools, The upper duck ponds in the western upper floodbasin supported either vernal pool floras, or moist ruderal vegetation, and exotic annual grasses.

Unvegetated saline runoff slopes and pickleweed swales dominated the lower floodbasins. Transition zone floras formed an irregular zone between the upper floodbasin grassland and vernal pool zone and the lower floodbasin floras. They were mound and swale zones in old floodbasins were confined to two low elevation grassland areas on either side of the abandoned stream levee. Above the duck ponds was another abandoned stream levee with a mixed flora of alkali grassland, dominated by *Distichlis* meadows, moist grasslands, annual exotic grassland, and degraded vernal pools, The upper duck ponds in the western upper floodbasin supported either vernal pool floras, or moist ruderal vegetation, and exotic annual grasses.

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The floodplain flora could subsequently be divided into three distinct vegetation zones: (1) the upper floodbasin grassland and vernal pool zone, (2) the intermediate or transition zone, and (3) the lower floodbasin pickleweed swale and unvegetated zone (Figure 1).

Soil and Hydrological Characterisitcs

Soil Salinity Profiles

Soil profiles on the Warm Springs floodplain in general were significantly more saline in the subsoils at one meter of depth than in the surface horizons (t statistic = -8.079, df = 35, $P < 0.001$). Vegetated surface horizons were significantly less saline than subhorizons at one meter of depth (t statistic = -6.782, df = 8, $P < 0.001$) on the upper floodplain, and on the lower floodplain (t statistic=-5.196, df = 8, $P<0.001$). Mean soil salinities were, however, higher overall on the lower vegetated floodplain in both the surface and subsoils (Table 2,3).

The upper floodplain surface soil horizons were significantly less saline than those of the lower floodplain (t statistic = 4.347, df = 8, P = 0.002). The surface soil horizons of vegetated soils were significantly less saline than those of unvegetated soils on the upper floodplain (t statistic = 6.462, df = 8, $P< 0.001$), and on the lower floodplain (t statistic = 3.647, df = 8, $P<0.025$).

Soil PH Profiles

The average pH ranges of soil profiles in all of the vegetation types in February 2001 significantly increased with increasing depth (t = 43.517, $P<0.001$). Soil pH tended to be neutral to slightly alkaline in the subsoil horizons of all of the vegetation types, and in the surface soils of pickleweed swales and unvegetated soils. The surface soil pH lower in the grasslands and lower elevation transition zone than in the other vegetation types. It was neutral to slightly alkaline in the upland grasslands, vernal pools and higher elevation transition zones and slightly acid in the lower elevation transition zone (Table 4).

Soil Morphology

Soil morphology was compiled and averaged from the profile data as soil appearance per horizon and thickness of each soil horizon for the six vegetation types. The grassland and transition zone soils (Figure 9 A, B, C) had three distinct soil horizons; a mollic surface horizon with a high humic content, a gray organic clay subhorizon beneath the mollic horizon, and an ochre colored inorganic parent clay below the gray agrillic meter of depth (Figure 14) during the rainy season were generally higher than surface soil salinities. Surface soil salinities were also generally higher in the lower floodbasins than in the upper floodbasins. The boundary between the variably saline lower floodbasin and the non-saline upper floodbasin was the floristic transition zone, which was also an edaphic boundary between the saline lower floodbasin and the non-saline upper floodbasin soils.

Spatial Soil PH

Spatial soil pH was measured in Feb 2001 (Figure 15) and proved to be quite variable, ranging from a mildly alkaline 8.0 to slightly acid 6.5. Vernal pool and grassland vegetation types had variable pHs, ranging from 6.0 to 8.0. Upland ruderal grasslands and the higher elevation transition zones were slightly acid to neutral, while the lower floodplain pHs ranged from 8 to 8.5 in saline evaporate depressions and pickleweed swales to 7.0 in some pickleweed swales and lower elevation transition zone areas.

Standing Water Salinity

Standing water salinities were measured throughout the wetland in impoundment's, vernal pools, temporarily flooded grasslands, and in the tidal pools along the railroad levee during February 2000 (Figure 16). Water salinities were generally low in grassland and vernal pool areas, and slightly elevated in the upland erosional basins. Water salinities were highest in the transition zones, pickleweed swales, and in the unvegetated swales.

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DISCUSSION

Relict Seasonal Wetland Sites

Relict vernal pool floras in the south bay were found exclusively on historic interfluvial basins and floodplain soils in both Santa Clara and Alameda Counties. The widespread occurrence of persistent species such as *Downingia pulchella* and *Eleocharis macrostachya* suggests that vernal pool wetlands and wet meadows were once widely dispersed, and may have originally occurred on the lower margins of floodplains and flood basins throughout the south bay. Relict vernal pool floras were most often found in seasonally flooding topographical depressions in fallow agricultural fields. Historically, vernal pool complexes probably occurred in low salinity soils within low-lying

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Since mound and swale zones, the duck ponds, and the saline seasonal habitat at Warm Springs occur in abandoned floodbasins associated with a prominent inactive natural stream levee, this brings up the interesting possibility that this mound and swale topography may have been characteristic primarily of the older terrains on alluvial fans where streams have long abandoned their levees and adjacent floodplains. The frequent seasonal flooding of basin terrains by active streams would have periodically buried and reburied floodbasin floors with silts and clays associated with stream overbank flooding. Such a dynamic depositional environment would not likely develop the complex mound and swale terrains such as those found in the abandoned floodasins at Warm Springs today (Lajoie, pers.com. 2003a). In this case, mound and swale terrains may have been characteristic of agrillic soils in abandoned basins flooded only by seasonal rainfall and rainfall runoff over a long period of time.

This isn't to say that seasonal wetlands didn't occur in active floodbasins, only that the topographies of active basins probably were not of the mound and swale type found within the Warm Springs inactive floodbasin and stream levee complexes. Historical references to seasonally flooded meadows, pasturelands, "frog ponds" and large-scale flooding of low lying areas with muddy standing water are typical of the vague historical descriptions of what active floodbasins around Alviso, San Jose and Palo Alto might have been like. Regardless of the relative ages of alluvial fan terrains around southern San Francisco Bay, the distribution of relict floras today in active and abandoned stream and flood basin complexes probably reflects, in part, their historic distributions as well.

The Jaccard's presence-absence cluster analysis divided the relict sites into two clusters that reflect both site size and historic land use. Smaller derelict farmed sites had a lower richness of vernal pool species, and lacked any traces of the mound and swale topography preserved on the Warm Springs site. The preservation of historic vernal pool complexes, together with the large size of the site could account for the high richness of the vernal pool floras at Warm Springs. Soil disturbances such as plowing and discing that degrade vernal pool topographies are likely responsible in part, for the attenuation of relict floras and the absence of vernal pool complexes on the former agricultural sites. Persistent, widely dispersed species such as *Downigia pulchella* and *Eleocharis macrostachya* are those species that are probably most tolerant of chronic soil disturbances.

Warm Springs Seasonal Wetland

The profile morphology of floodplain soils varied with vegetation type. Vegetation in which grasses were a significant component of the flora (Grassland and higher elevation transition zones), were three -horizon soils, possessing a mollic surface horizon characteristic of grassland soils that the soils of the other vegetation types lacked. The absence of a mollic horizon in most of the vernal pool soils is probably a consequence of the absence of grasses in vernal pool floras. Vernal pools do however have an organic agrillic horizon, characteristic of vegetated soils in general in the Warm Springs floodbasins. The dark, saline upper soil horizon of pickleweed swales may be a consequence of anaerobic conditions in these soils during seasonal flooding, which produces dark hued, reduced iron compounds under similar conditions in saturated saline salt marsh soils. The uniform ochre colored clay of the unvegetated runoff slopes and upper floodbasin erosional zones is the parent soil of the floodbasins. It is largely unweathered due to a lack of a vegetative cover, which results in poor vertical water infiltration through the profile, and continuous erosion of the surface soils.

The salt distribution pattern of the vegetated profiles is characteristic of soils in within the surface horizon is seasonally leached, translocationg surface salts into adjacent subsoil horizons (Mall 1969). Thus the surface horizons tend to be less saline than the sub horizons at a depth of one meter. The salt distribution pattern in the unvegetated soils, in which the surface horizon is more saline than the sub horizons, is typical of soils in which salts accumulate over time as a consequence of repeated flooding and drying, without seasonal leaching (Birkland 2000). Vegetated soils at Warm Springs apparently have surface soil horizons that are effectively permeable, even though quite agrillic, while those of unvegetated soils do not. The higher permeability of vegetated soils likely results, in part, from the presence of the vegetation itself. Vegetated soils in general, especially grassland soils, have extensive, shallow root networks, which may act as conduits that increase vertical infiltration of water through them. The accumulation of organic matter in vegetated soils improves permeability and water retention in soils as well (Birkland 2000).

Long-term impoundment of flooded basins with fresh water also appeared to leach salts out of surface soils, since vernal pools and fresh water pickleweed swales were subsaline or non-saline. Fresh water flooding typically reduces surface soil salinities in seasonal wetlands in Suisun Marsh (Mall 1969), and probably does so in vernal pools and fresh water impoundments at Warm Springs as well.

The source of salt in the Warm Springs soils is probably a shallow, saline groundwater table, known to underlie the southern portion of the Alameda Creek alluvial fan (Davies 1966). Salinities increase in surface soils as they dried during the summer. This is evidently due to salt migration upward through the soil profile from the saline groundwater table below. Since salt concentrations are higher throughout soil profiles in the lower floodbasins than in the upper floodbasins, the saline groundwater table is probably closer to the surface at lower elevations. Salts migrating upward apparently permeate the entire profile to a greater degree in the lower floodbasins than in the upper floodbasins, resulting in the greater overall soil profile salinities on the lower floodplain.

Salt concentrations in surface soils on the lower floodplain may be typically too high for all of the residual salts in them to be leached completely during the rainy season.

Erosional instability of some unvegetated surface soils in the upper floodbasins has exposed the subsoils, creating saline basins or depressions, salt scalds and bare soil slopes throughout the grasslands. Unvegetated soils also occur in the lower floodbasins. These are typically continuously eroding soils and are variably saline. The gradual loss of the non-saline topsoil in the floodbasins by surface water erosion is one factor that apparently transforms fresh water seasonal wetlands and upland grasslands into saline habitats at Warm Springs. Bare soil habitats in saline environments are often more saline than their vegetated counterparts. This is largely due to increased evaporation of water from soils unshaded by a vegetative cover and the seasonal migration of subsoil salts to the surface in the summer as the soils rapidly dry. Because these soils are continuously erosive drainage surfaces, there is no impoundment of fresh water, or vertical infiltration of fresh water through the soil profiles. As a consequence, there is little or no seasonal leaching of salts from surface soils (Amiaud et.al.1998, Iacobelli and Jeffries 1991). The high rate of erosion coupled with the seasonally elevated salinities probably inhibits establishment of a continuous vegetative cover on these soils. Where vegetation did occur on saline erosional soils in the lower floodbasins at Warm Springs, it was sparse and dominated by halophytes. In the upper floodbasins on the slope transitions of the stream levee, the flora of these erosive zones was a unique halophyte assemblage dominated by *Hemizonia pungens, Juncus bufonius, Sueda moquinii* and the colonial cyanobacterium, *Nostoc.* On the lower floodplain, salt tolerant transition zone species were sparsely distributed on

Warm Springs. Bare soil habitats in saline environments are often more saline than their vegetated counterparts. This is largely due to increased evaporation of water from soils unshaded by a vegetative cover and the seasonal migration of subsoil salts to the surface in the summer as the soils rapidly dry. Because these soils are continuously erosive drainage surfaces, there is no impoundment of fresh water, or vertical infiltration of fresh water through the soil profiles. As a consequence, there is little or no seasonal leaching of salts from surface soils (Amiaud et.al.1998, Iacobelli and Jeffries 1991). The high rate of erosion coupled with the seasonally elevated salinities probably inhibits establishment of a continuous vegetative cover on these soils. Where vegetation did occur on saline erosional soils in the lower floodbasins at Warm Springs, it was sparse and dominated by halophytes. In the upper floodbasins on the slope transitions of the stream levee, the flora of these erosive zones was a unique halophyte assemblage dominated by *Hemizonia pungens, Juncus bufonius, Sueda moquinii,* and the colonial cyanobacterium, *Nostoc.* On the lower floodplain, salt tolerant transition zone species were sparsely distributed on these soils. They were otherwise bare, and formed extensive salt flats in the lower floodbasins in the summer.

The distinctive associations of fresh water vernal pool species and salt marsh halophytes in the vernal pools and abandoned duck ponds, and exotic grasses with halophytes in the upper floodbasins (Figure 23) are apparently the result of the stratified distribution of salts in upper floodbasin soil profiles. This stratification has created two distinctive root zones in upper floodplain soils: the non-saline surface horizon and the variably saline sub horizons (Figure 24).

The majority of halophytes in the Warm Springs grasslands were also species common to upper peripheral salt marshes and alkali flats, and no doubt are tolerant of drier conditions found in seasonally moist grasslands. Halophytes typical of prolonged flooding in seasonal wetlands, such as *S. virginica,* were absent from grassland floras. In the PCA analysis, the lower salinity wetland vegetation gradient tracked the distribution of *Plagiobothrys* through the fresh water seasonal wetland vernal pools, the subsaline portion of the transition zone, and the subsaline pickleweed swale floras. This pattern of distribution is apparently relict, reflecting the historical distributions of the more salt tolerant vernal pool species in the original native wetland floras of the south bay.

While *Downingia pulchella* is presently restricted in distribution to vernal pools for the most part in the 1998 surveys, existing historical records of both *Downingia* and *Plagiobothrys* suggest broad distributions similar to the subsaline gradient seen in the PCAs. *Plagiobothrys* occurred historically in high coastal salt marshes, and *Downingia pulchella* was described as being "abundant and of rank growth" in the salt marshes near present day Union City by Jepson in 1901 (Baye etal.2000).

Other species found in the Warm Springs vernal pool floras today were also historically associated with saline seasonal wetlands and tidal salt marshes. *Lasthenia glaberrima* was recorded "near salt marshes" by Behr in 1888, and *L conjugens* from subsaline soils in the bay from Antioch to Newark (Greene 1894, Jepson 1911), and more recently in diked baylands in Solano County (Baye 2000). Carl Sharsmith collected *L. glabrata* from "dense colonies on the valley levels directly adjacent to tidal marshland" north of Milpitas in 1952 (CWS Herb. Records). *Castilleja ambigua* was common on the borders of salt marshes in Alameda and Berkley (Greene 1894, Jepson 1911). The 19th century botanist Joseph Burtt-Davy noted extensive wildflower meadows with species characteristic of vernal pools and wet grasslands in historic salt marsh and subsaline seasonal wetland habitats around the south bay (Baye 2000).

Historically, the distributions of many vernal pool annuals included the saline borders and upper peripheral salt marshes, including what would have been the subsaline transition zones and pickleweed swales of saline seasonal wetlands like those at Warm Springs today.

In the modern floras at Warm Springs, the transition zones are probably the most altered of the wetland floras, have the fewest vernal pool native annuals in them and consist almost entirely of introduced species. Historically, transition zones at Warm Springs probably consisted of a mix of perennial pickleweed, wetland grasses, perennial and annual upland native grasses and native annual wetland species now largely confined to vernal pools. The present limited distributions of most of the vernal pool species at Warm Springs to the upper floodplain vernal pools are probably the result of at least two factors: (1) the loss of the high marsh to lower floodplain ecotones due to diking, agricultural drainage and salt pond construction, and (2) The invasion of existing saline habitats by halophyte perennials, subshrubs and annual grasses which may have displaced many of the native annuals once common in these habitats.

Vernal pools in the Warm Springs wetland today are refugia for native wetland annuals. This was well demonstrated in the PCA gradients by the clear segregation of the grassland floras from those of wetland habitats. Many exotic annual grasses are somewhat salt tolerant (Baye 2000), but apparently intolerant of the repeated or prolonged flooding of the seasonal wetland habitats at Warm Springs, as they are absent in the floras at the high end of the flooding gradient. The vegetation types in which grasses were absent had the highest percentages of native species, and those in which they were abundant had the greatest percentages of invasive species. The flood factor limits exotic grass dominance to the transition zones and uplands at Warm springs. If this were not so, exotic grasses would have displaced the native annuals long ago in the vernal wetlands as they have in the grasslands at Warm Springs and in wildflower prairies throughout most of California.

The vegetation gradient or coenocline in the Warm Springs flora, as based on the PCA results, had three sub gradients: one in the non-saline upper floodbasins and two in the variably saline lower floodbasins (Figure 25).

The upper floodbasin gradient segregated scattered vernal pools and vernal pool complexes from the surrounding grasslands along a flood gradient only, as no significant soil salinity gradient were present in most of the upper floodbasins. The situation in the lower floodbasins was somewhat more complex since both the soil salinity gradient and the flood gradient were well expressed there. The basic pattern from the PCA analysis was that of a coenocline in which high elevation grassy transition zone floras were replaced in turn by low grass transition zones, transition zones lacking grasses, and pickleweed swales along an increasing flood gradient. As the soil salinity increased, vernal pool annuals dropped out of the floras and were replaced by *Juncus bufonius*. A but are common in more "normal" rainfall years. Most notable of these latter pools are those dominated by *Lasthenia conjugens,* which is responsible for the beautiful yellow vernal pools so typical of Warm Springs.

There is little historical documentation of the floristic associations and appearance of the Warm Springs floodplain prior to land use disturbances and exotic plant invasions in relatively recent times. Soil maps, the relict flora, and sketchy historical record are the only sources of information available today. From this information, inadequate as it is, a general pattern of the character of the historic floodplain does emerge.

In the relict Warm Springs flora, the three general vegetation zones, (the non-saline grassland and vernal pool zone of the upper floodbasins, the saline transition zone, and the saline pickleweed swale zone of the lower floodbasins) were probably there historically as well.

Vernal pool complexes occur today in mound and swale zones in the upper floodbasins, and very likely have always been there, interspersed within a grassland habitat. Many native vernal pool annuals persist in the modern floras, but the floristics of the original local native grasslands is poorly known. In the relatively undisturbed lower southwestern area of the Warm Springs site, the edaphic boundary between the upper non-saline floodbasin and the lower salt-affected basin rim on geological maps (Figure 26A coincides with the modern floristic transition zone, and likely did so historically as well.

By extending the distribution of the transition zone to follow the historic edaphic boundary and then removing the modern duck ponds, levees, flood control channels, and the original local native grasslands is poorly known. In the relatively undisturbed lower southwestern area of the Warm Springs site, the edaphic boundary between the upper non-saline floodbasin and the lower salt-affected basin rim on geological maps (Figure 26A coincides with the modern floristic transition zone, and likely did so historically as well.

By extending the distribution of the transition zone to follow the historic edaphic boundary and then removing the modern duck ponds, levees, flood control channels and salt ponds, the historic transition boundary on the Warm Springs floodbasins may have looked something like the reconstruction in Figure 26B. The historic transition zone floras were probably a mix of native grasses and vernal pool annuals in subsaline soils. Halophytes such as *Juncus bufonius* and grasses would have been common in the more saline soils. The lower floodbasins most certainly would have had many of the pickleweed swales that persist there today and sketchy historical records also document a number of vernal pool annuals in these low floodbasin areas. Whether the extensive unvegetated salt flats, runoff slopes and hypersaline swales found in this zone on the Warm Springs site today were typical of this zone in floodbasins in general is unknown since there are no other similar surviving sites for comparison.

This is as much as can be reconstructed historically with any certainty in terms of the appearance of the original floodplain. It does suggest that the distribution of vernal pool annuals on the historic floodbasins surrounding southern San Francisco Bay was similar to the relict distribution of these species on the Warm Springs floodplain today. Many of the modern vernal pool species were apparently not confined necessarily to upper floodplain fresh water seasonal wetlands, but were probably most abundant there in the fresh water vernal pool complexes. Relict distributions of vernal pool species in the saline seasonal wetlands together with historical records also suggest that subsaline conditions were common not only in historic saline seasonal wetlands, but also in high tidal marsh borders, since many of these species have been documented there in the past as well.

Relict floras give only a fragmentary picture of the historic floras that they came from and the historic habitats that they were adapted to. The Warm Springs Seasonal Wetland is all that remains of the natural vernal pool habitats of the south bay. It gives us but a glimpse of a wetland habitat that has all but vanished in the wake of urbanization in the Santa Clara Valley.

Conservation and Management Considerations

The tendency for unvegetated, erosive soils on the Warm Springs floodplain to become saline over time is a characteristic of both the saline basin rim and the non-saline upper floodbasin soils. In both cases, subsurface salts are drawn into bare surface soils as they rapidly dry. This is a common characteristic of soils with high concentrations of subsurface soil salts or saline groundwater table.

At Warm Springs, glycophyte-dominated floras on the upper floodplain are replaced initially by a unique halophyte association of *Sueda moquinii* and *Hemizonia pungens* on denuded and continuously eroding grassland soils. Cooper's (1926) observation of *H. pungens* becoming common only after cultivation on floodplain grasslands suggests that it is a disturbance invasive as well as an indicator of alkaline and saline soils since it associates primarily with halophyte species. The invasion of an area by *H. pungens* and *S. moquinii* may be an early phase of the replacement of fresh water seasonal wetland and non-saline upland grassland habitat by the saline seasonal wetland habitat in erosive soil environments or it may simply be a flora characteristic of continuously erosional soils in relict floodbasins in general. But these two species are certainly indicative of soils that have recently lost the original surface soil horizon. At Warm Springs this appears to have occurred as a result of rainwater erosion on soils in which the vegetative cover has been damaged probably by the extensive trenching of some of the soils along the old stream levee slope for drainage purposes in the recent past. Any substantial loss of a stabilizing vegetative cover on grassland soils will likely result at some point in the salinization of the exposed soil surface as it erodes.

A continuous vegetative cover not only stabilizes these erosion-prone soils, but also mediates soil water loss, and establishes salt leeching zones in the surface soils, keeping salt buildup in the shallow root zone to a minimum. Any management of restoration strategies should take this into consideration, as damage to the vegetative cover results in rapid erosion in these friable agrillic soils.

Some portions of the upper floodplain appear to be derelict agricultural lands, notably the areas immediately north of the upper duck pond complex. The present flora here consists of invasive grassland, degraded vernal meadows and seasonally flooded alkali grasslands. This area was probably originally part of an abandoned stream levee. These areas would have been less prone to seasonal flooding than the basin areas adjacent to it, and thus more suitable to agriculture than adjacent inactive floodbasins. Successful construction of vernal pool basins in such areas would depend upon the suitability of old stream levee soils to retain standing water for any period of time.

The abandoned upper floodbasin duck ponds, however, support typical vernal pool floras amid a mosaic of invasive weeds and grasses, but only in suitable topographic depressions that pond water during the rainy season. The soils in the upper duck ponds are quite capable of supporting vernal pools under favorable conditions because they occur in a floodbasin and were historically probably part of the same mound and swale complex south of the duck pond complex in which vernal pools are abundant today. In the upper duck ponds that seasonally pond water, local native vernal pool species such as *Psilocarphus brevissimus, Plagiobothrys stipitatus, Downigia pulchella, Navarettia prostratum*, and *Limosella acaulis* have readily colonize them. The suitability of the soil together with a vigorous local source of native vernal pool colonizers make the duck pond areas good candidate sites for future vernal pool restorations. This would also be true of any degraded non-saline wetland area within either of the upper floodbasins on the Warm springs site.

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Table 1. Importance Value indices for six vegetation types in the Warm Springs Seasonal Wetland, June 1998.

SPECIES	GRASSLAND	HIGH ELEVATION TRANSITION ZONE	LOW ELEVATION TRANSITION ZONE	PICKLEWEED SWALE	DUCK POND	VERNAL POOL
Hemizonia pungens	16					
Lolium multiflorum	176	63	53			
Hordium M. leporiunum	67	21	28			
Frankenia salina	48		13		12	60
Salicornia virginica		38	38	140		13
Cotula coronopifolia			69	31		23
Plagiobothrys stipitatus			69	17	35	34
Juncus bufonius		74				
Limocella acaulis				94	23	
Lythrum tribractiatum					68	
Eleocharis macrostachya					16	
Downingia pulchella					64	53
Distichlis spicata					79	34
Lyhrum hyssopifolia						25
Lasthenia conjugens						19
Psilocarphus brevissimus						67

Table 2. Mean apparent soil salinities of five habitats in the Warm Springs Seasonal Wetland from soil mapping data, February 2001.

	Depth in Soil Profile					
Vegetation Type	0 cm	30 cm	60 cm	90 cm	Mean	N
Pickleweed Swale	1.9	2.1	2.7	3.2	2.5	12
Lower Elevation Transition	0.9	1.2	1.9	1.9	1.5	5
Higher Elevation Transition	1.6	1.6	2.4	2.3	2.0	8
Vernal Pool	0.1	0.7	1.3	1.5	1.0	6
Grassland	0.1	0.3	1.0	1.0	0.6	7
Bare Ground	0.9	3.5	3.1	3.0	3.5	8
Mean	0.9	1.2	1.9	2.0		

Table 3. Results of unpaired t tests between surface soil salinity (0-15 cm) and subsoil salinity (90-105 cm) in four regions of the Warm Springs Seasonal Wetland, February 2001.

Location	DF	F statistic	P	Alpha
Unvegetated lowwer floodplain	8	6.997	0.000	p<0.001
Unvegetated upper floodplain	8	5.900	0.000	p<0.001
Vegetated lower floodplain	8	-7.245	0.000	p<0.001
Vegetated upper floodplain	8	-12.500	0.000	p<0.001

Table 4. Mean soil pH for six habitats in the Warm Springs Seasonal Wetland from soil mapping data, February 2001

	Depth in Soil Profile					
Vegetation Type	**0 cm**	**30 cm**	**60 cm**	**90 cm**	**Mean**	**N**
Pickleweed Swale	7.8	8.0	8.0	8.0	7.9	12
Lower Elevation Transition	6.8	7.0	7.8	8.0	7.4	5
Higher Elevation Transition	7.5	7.8	8.0	8.0	7.8	8
Vernal Pool	7.5	7.8	8.0	8.0	7.8	6
Grassland	7.1	7.5	8.0	8.0	7.6	7
Bare Ground	8.0	8.0	8.0	8.0	8.0	8
Mean	7.4	7.7	7.9	7.9	7.7	

Table 5. Eight vegetation types in the Warm Springs Seasonal Wetland as classified by Principle Component Analysis , June 1998.

SPECIES	GRASSLAND	HIGH ELEVATION TRANSITION ZONE	LOW ELEVATION TRANSITIONZONE	SALINE PICKLEWEED SWALES	SUSALINE TRANSITION ZONE	SUBSALINE PICKLEWEED SWALE	VERNAL POOL	DUCK POND
Hemizonia pungens	16							
Lolium multiflorum	176	64	28					
Hordium M. leporiunum	67	66	32					
Frankenia salina	48	27		19	28		30	17
Salicornia virginica		59	76	148	48	136	16	
Cotula coronopifolia				137	57	32	5	
Plagiobothrys stipitatus					64	13	49	45
Juncus bufonius			119					
Limocella acaulis						99		15
Distichlis spicata							17	65
Downingia pulchella							50	29
Psilocarphus brevissimus							27	4
Lyhrum hyssopifolia					54			7
Lythrum tribractiatum								48
Eleocharis macrostachya								49
Lasthenia conjugens								7

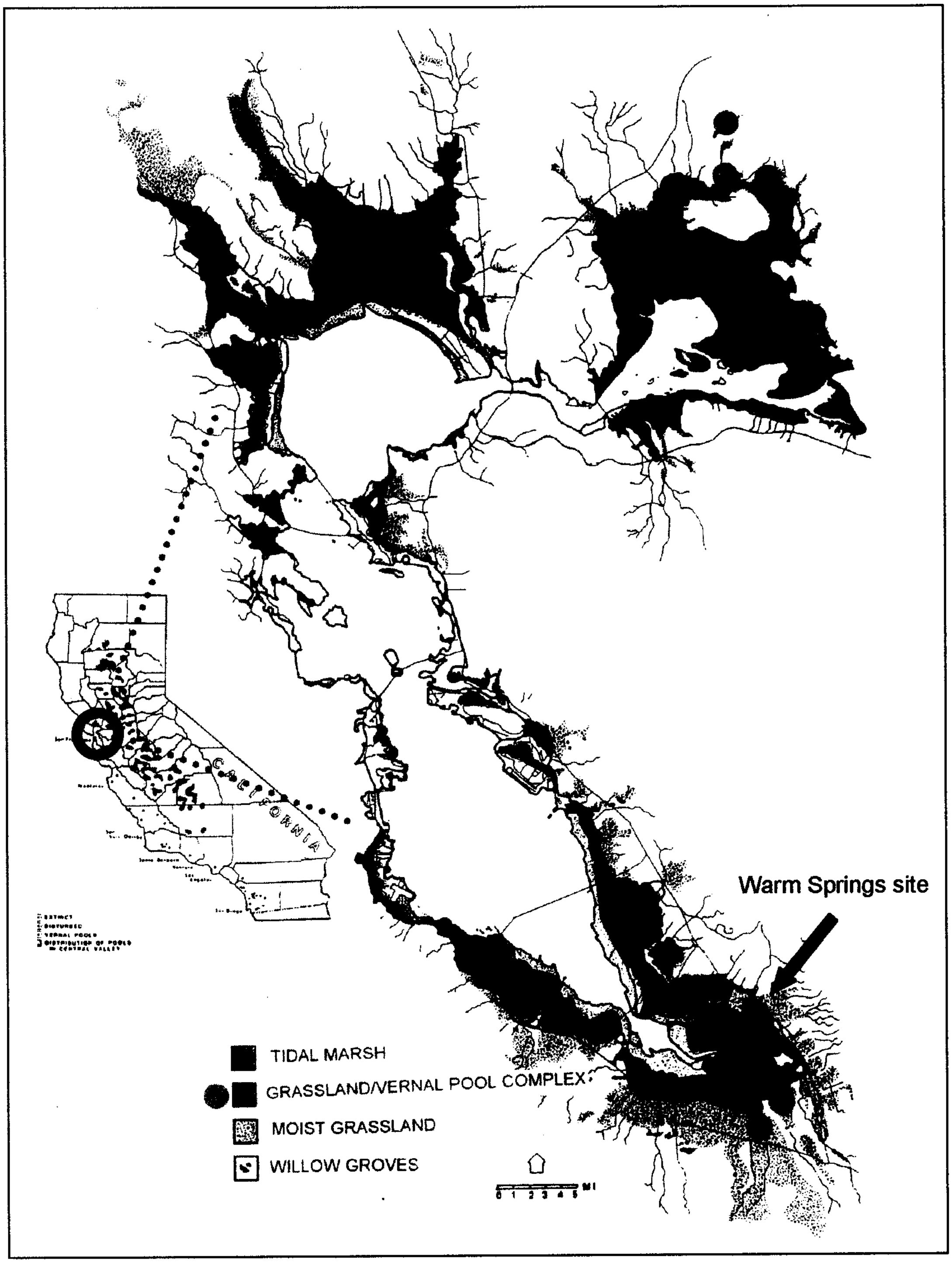
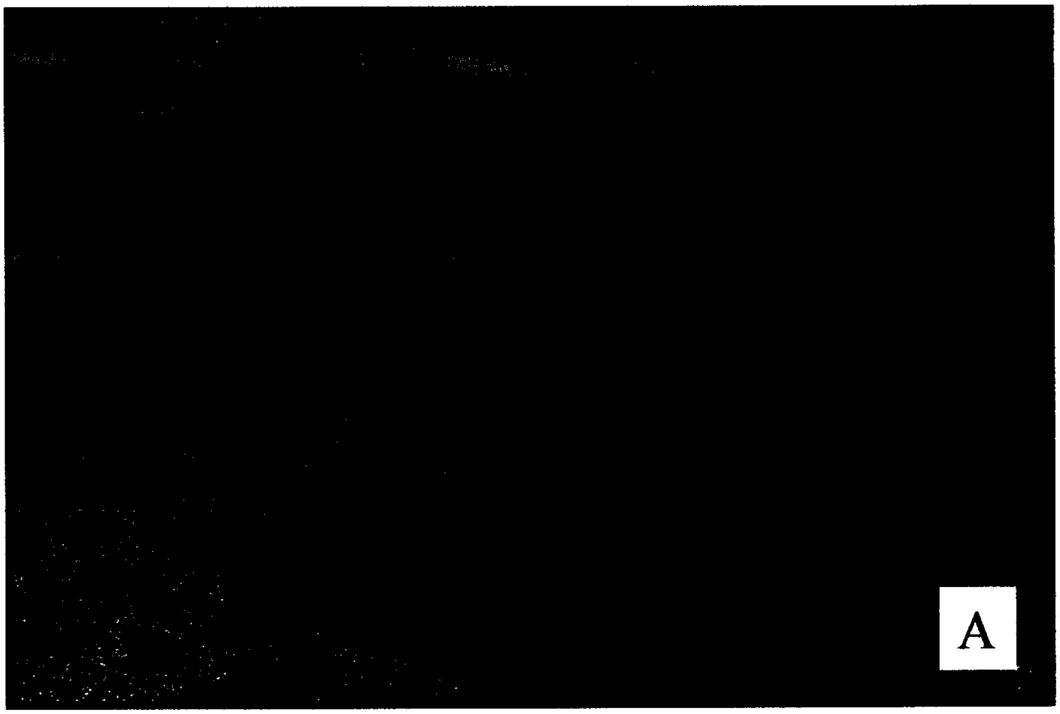


Figure 1. Historic distribution of wetlands in San Francisco Bay, circa 1800. Modified from Goals Project 2000, Helly and Lajoie, 1979



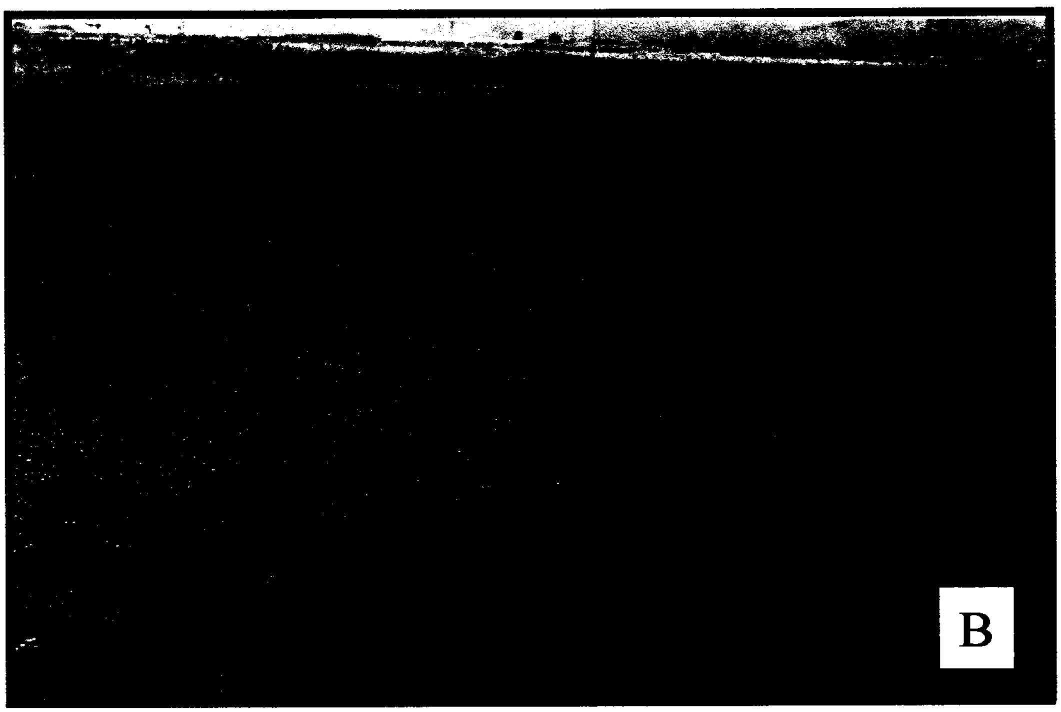


Figure 2. Relict vernal pool sites.
A: Vernal pool on derelect agricultural land in Alviso, Santa Clara Co., CA.
B: Vernal pool in abandoned duck hunting pond, Fremant, Alameda Co., CA.

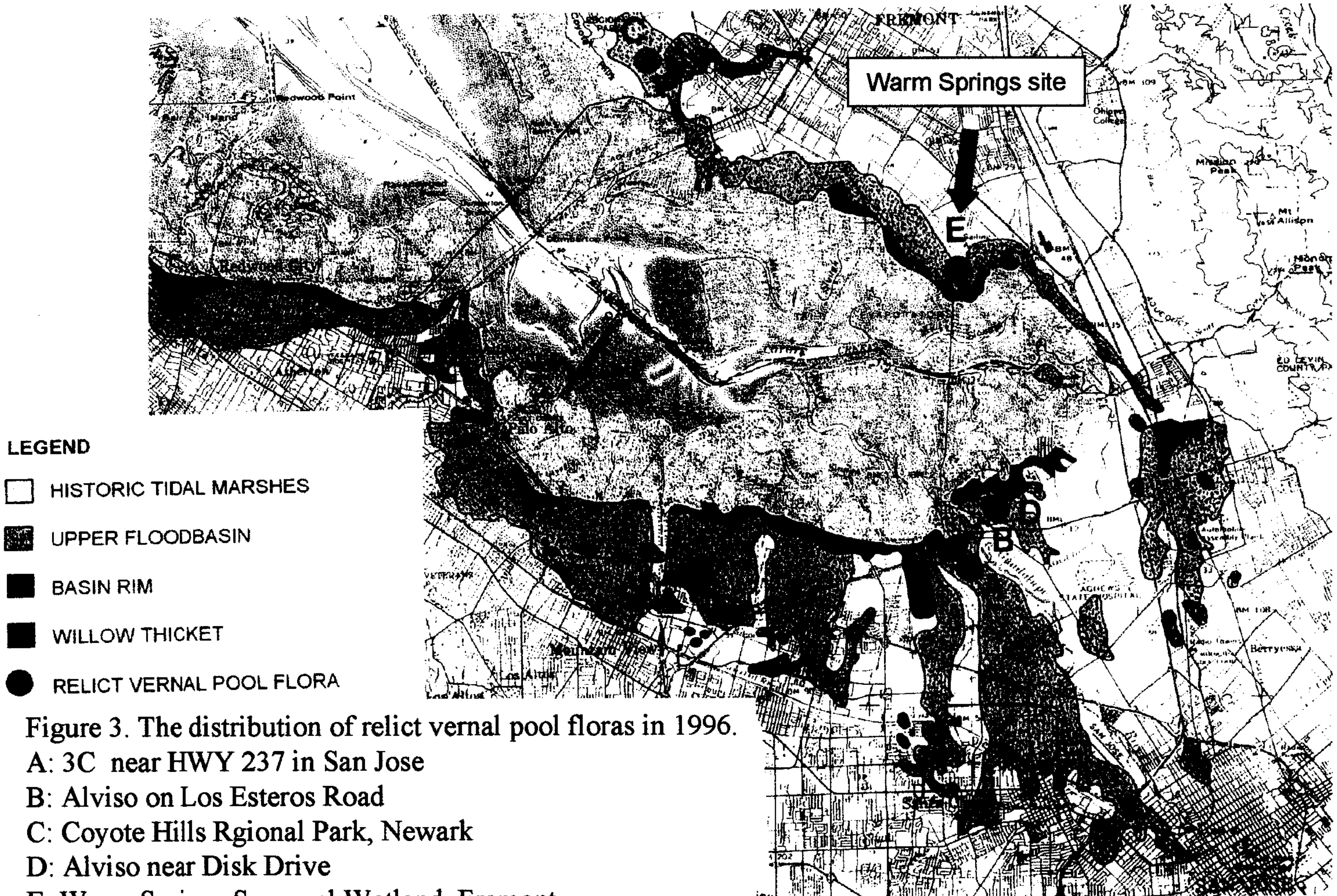
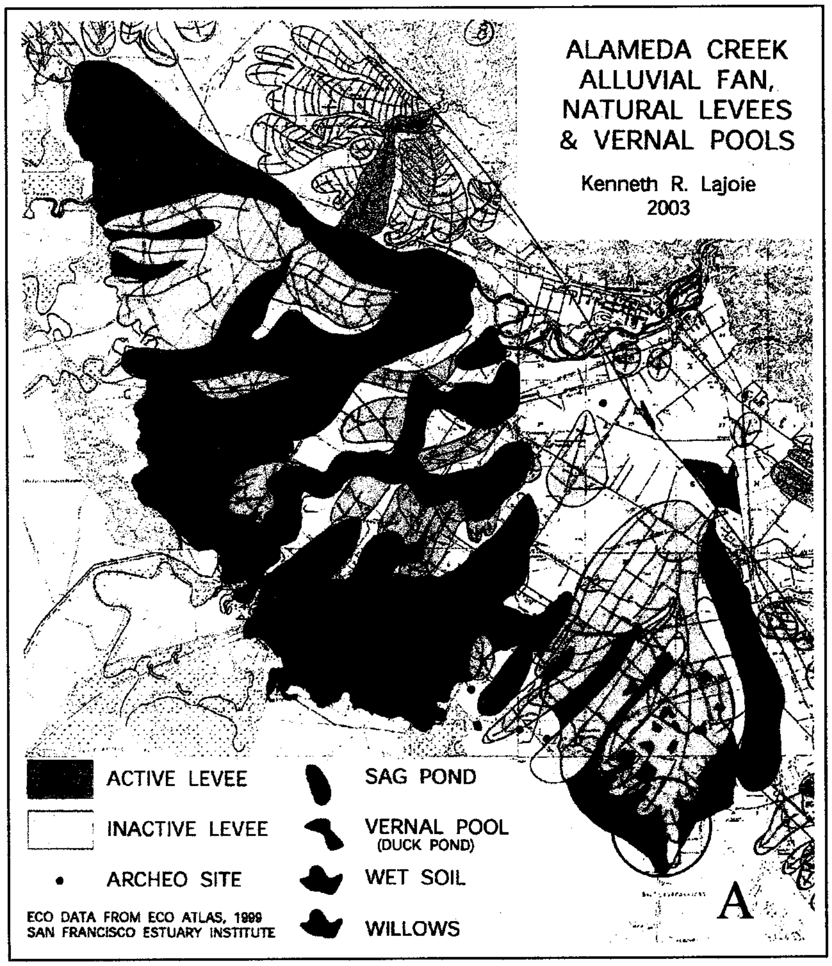


Figure 3. The distribution of relict vernal pool floras in 1996.
A: 3C near HWY 237 in San Jose
B: Alviso on Los Esteros Road
C: Coyote Hills Rgional Park, Newark
D: Alviso near Disk Drive
E: Warm Springs Seasonal Wetland, Fremont
Modified from Helly and Lajoie 1979



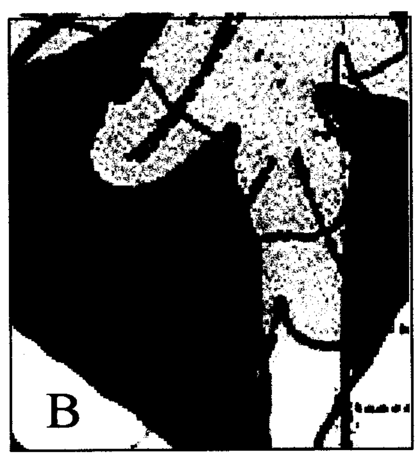


Figure 4. A: The Alameda Creek alluvial fan. B:Detail of Warm Springs Seasonal Wetland site in Figure 5.Yellow:inactive stream levee, Green: abandoned floodbasins. Modified after Lajoie, 2003.

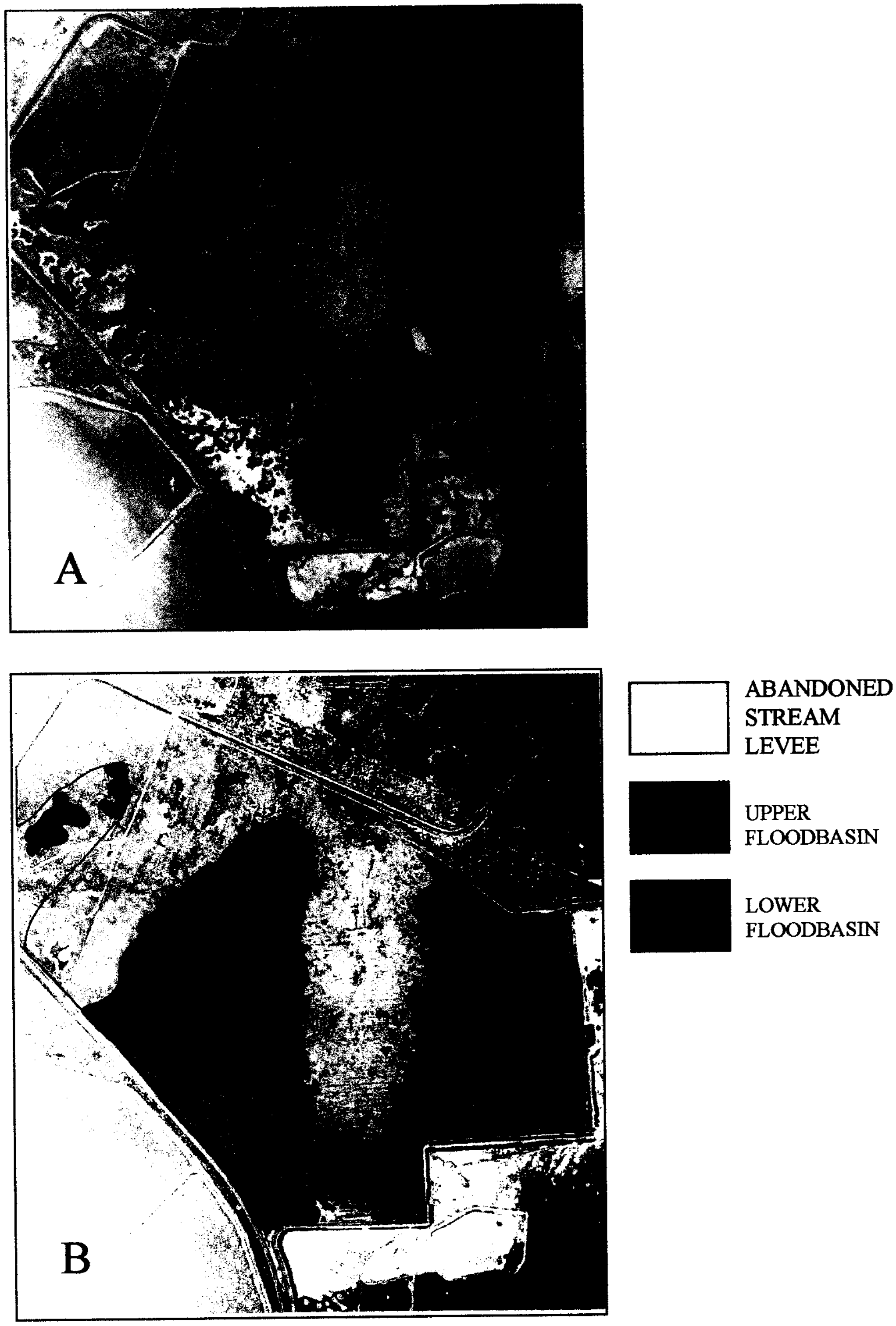


Figure 5. A: Warm Springs Seasonal wetland site, May 1999.
B: geomorphology of the Warm Springs floodplain.

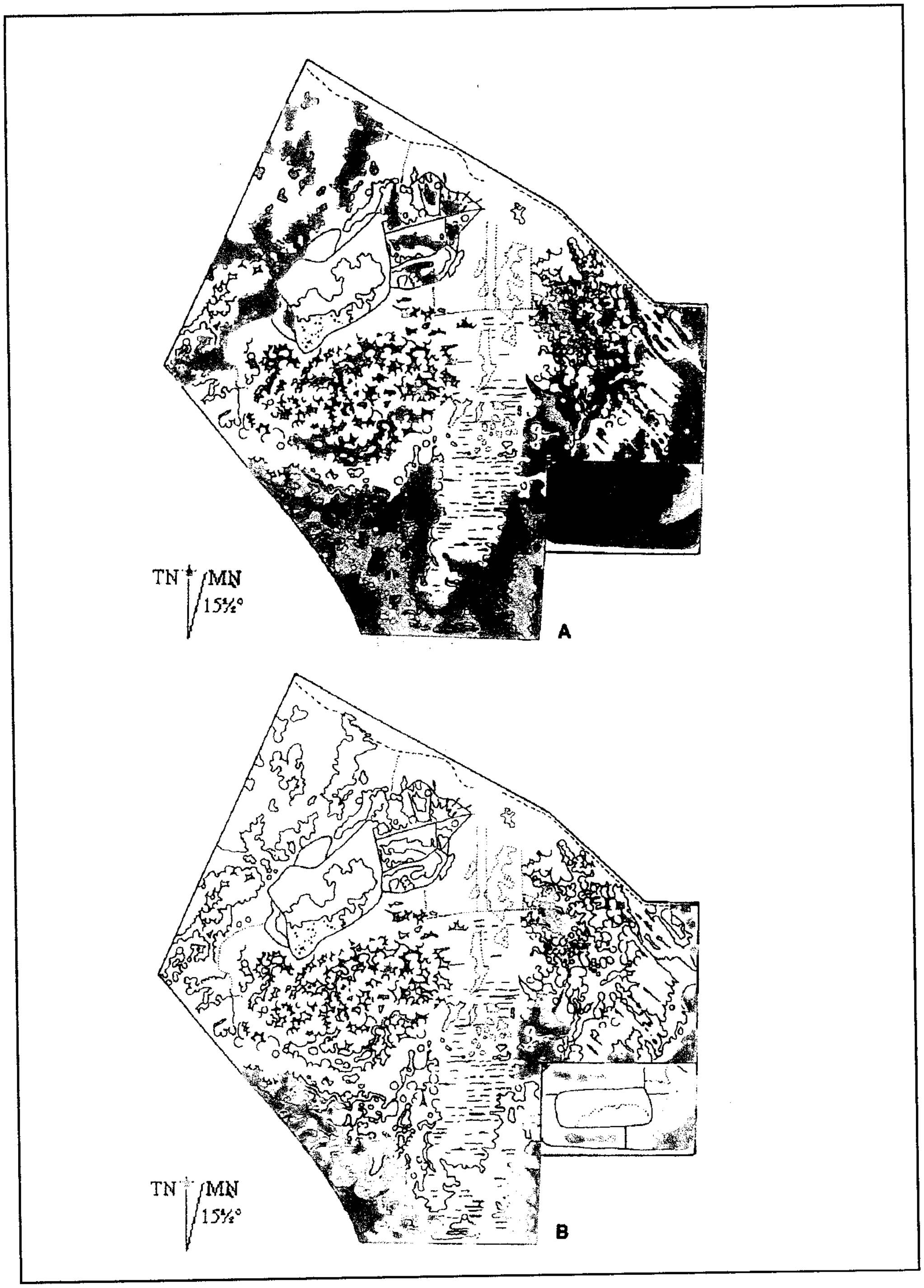


Figure 6. Winter flood zones (blue) and saline runoff slopes (orange) in the Warm Springs Seasonal Wetland. A: high rainfall winter, 21 February 1998, 21 inches of rain to date, B: low rainfall year, 21 February 2000, 7 inches of rainfall to date.

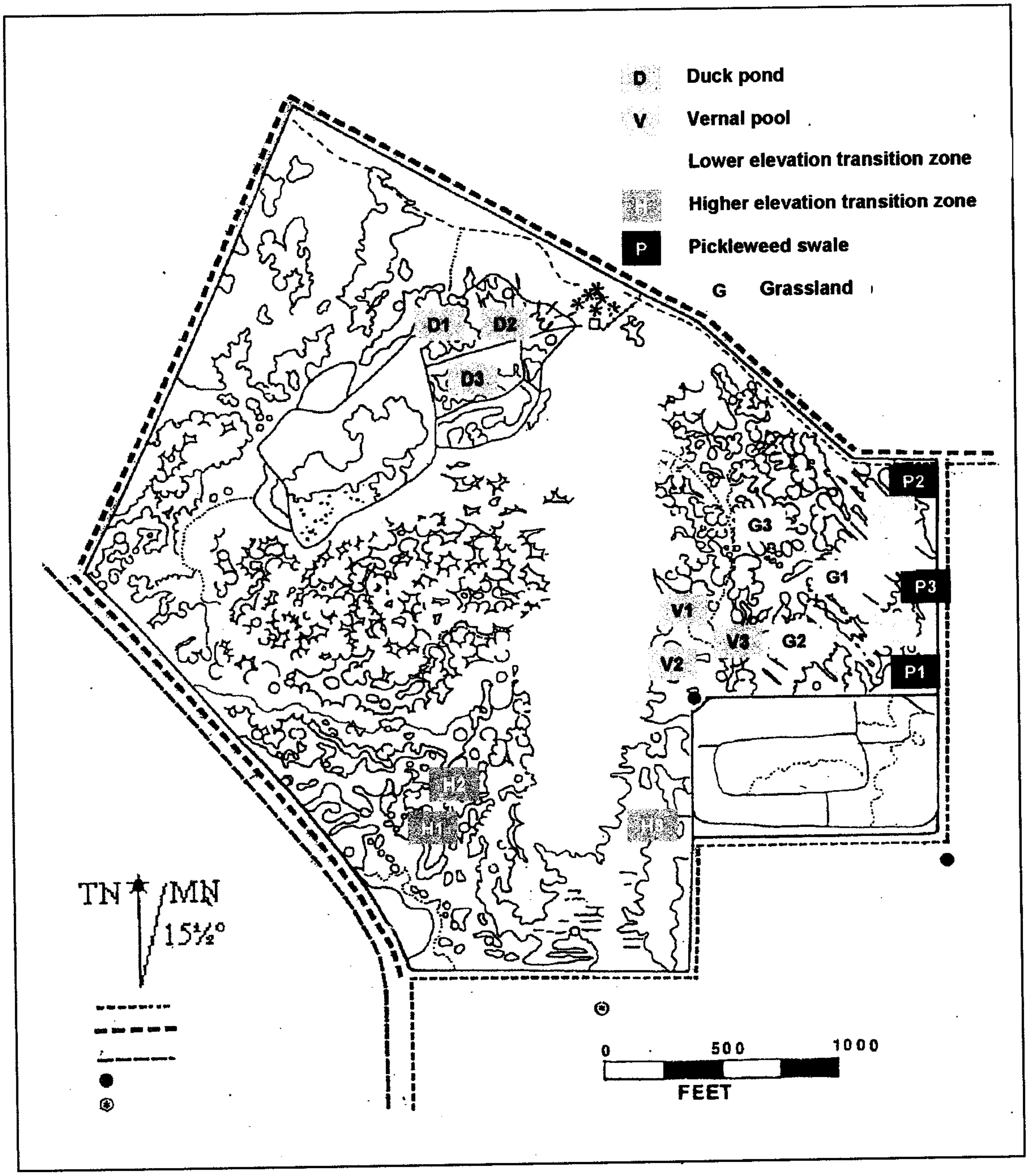


Figure 7. Locations of vegetation survey plots in the Warm Springs Seasonal Wetland, May 1998.

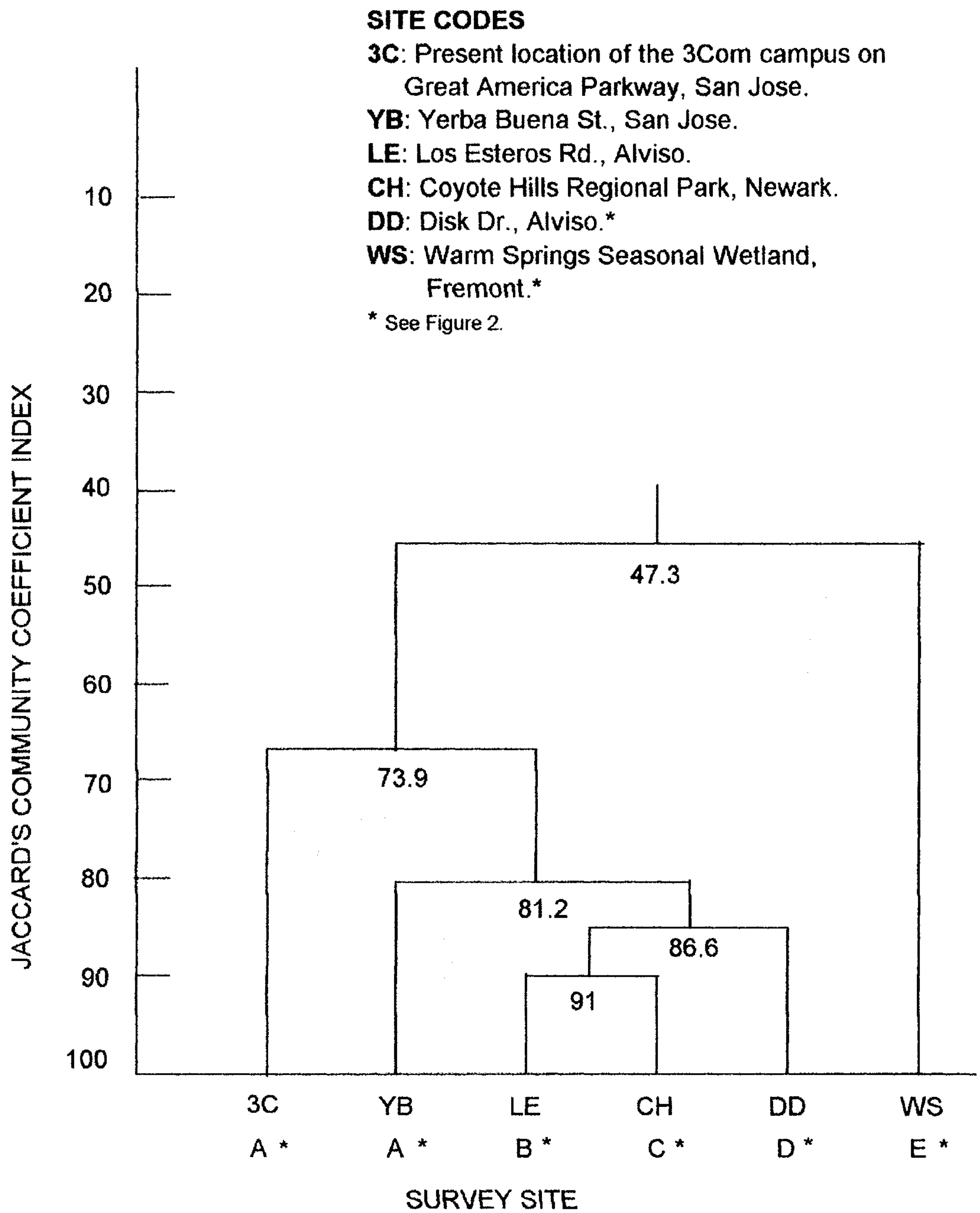


Figure 8. Jaccard's presence - absence cluster analysis of species composition of six relict vernal pool floras in the southern San Francisco Bay area from 1996 surveys. * location of survey sites in figure 3.

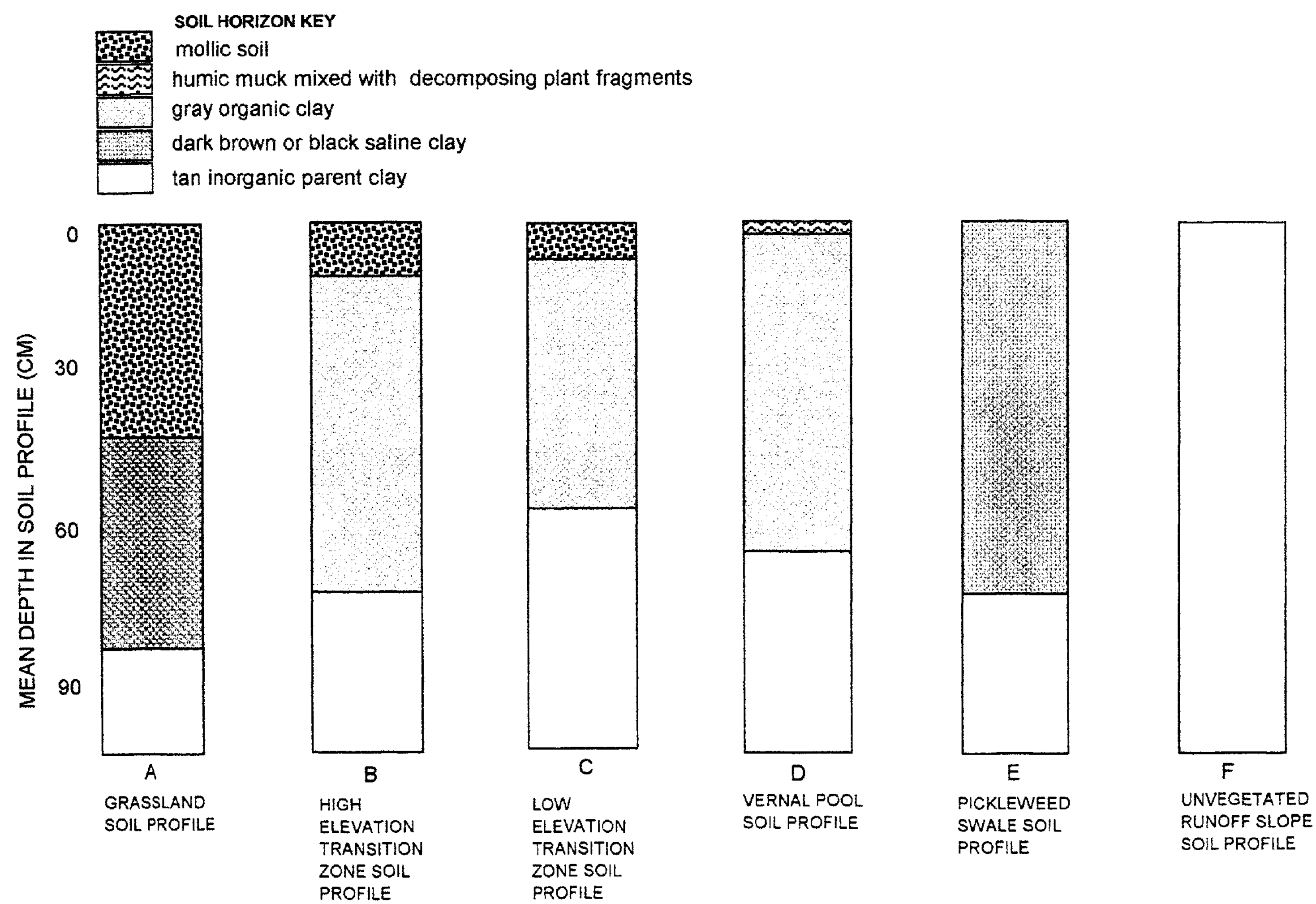


Figure 9. Soil profiles of six vegetation types on the Warm Springs floodplain.

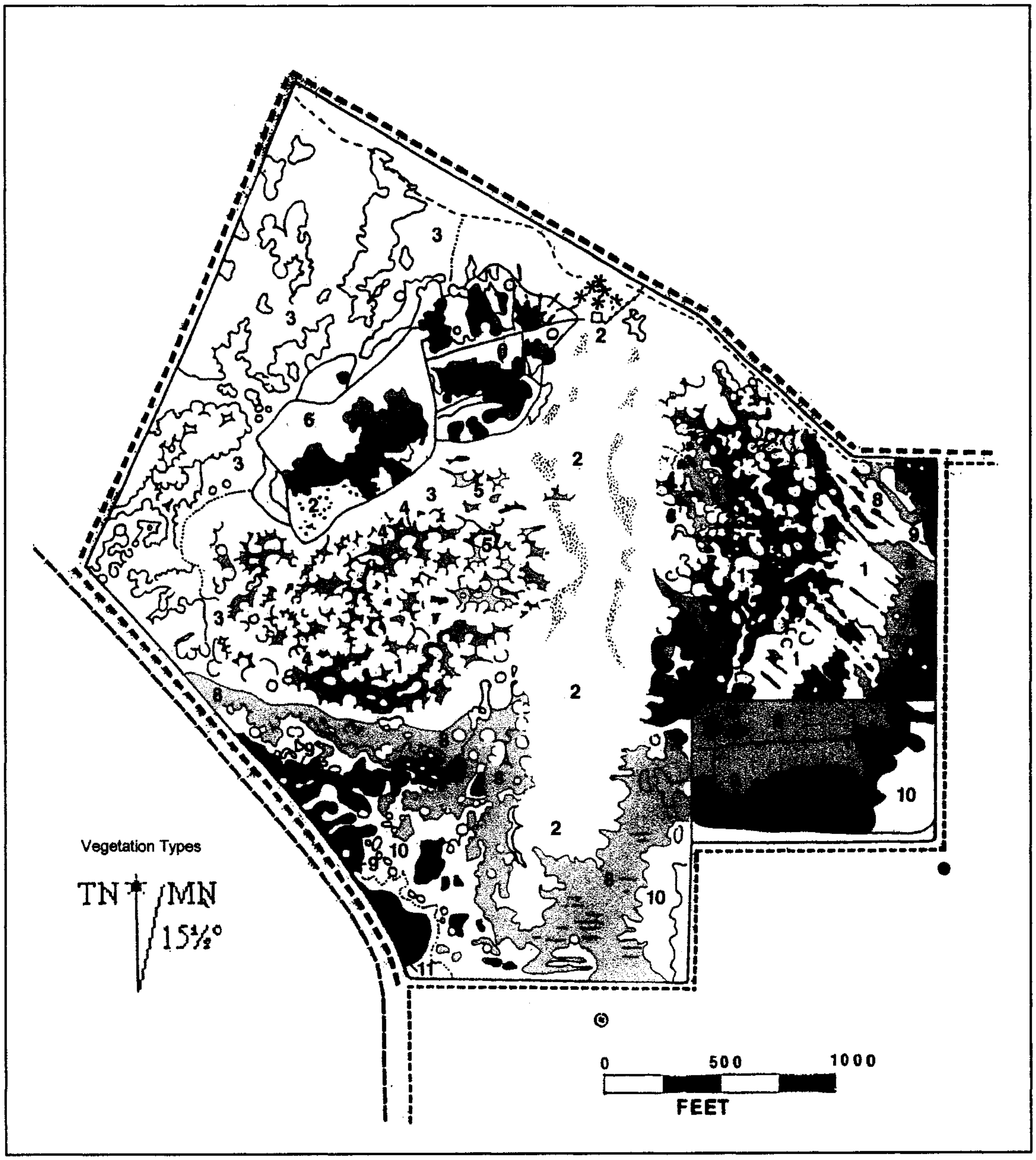


Figure 10. Vegetation distribution in the Warm Springs Seasonal Wetland, 1998. (Map legend on the following page).

VEGETATION MAP LEGEND

VEGETATION TYPES

UPPER FLOODPLAIN

1 — Exotic annual grassland: primarily *Lolium multiflorum, Hordeum murinum ssp. Leporinum,L deprssum, Bromus diandrus, B. hordeaceous, Leymus triticoides*

2 — Upland ruderal/annual grassland on abandoned stream levee: *Lactuca serricola* thickets, *lolium multiflorum-bromus diandrus* mix *Baccharis pilularis* thickets in duck pond

3 — Differentially flooded exotic annual grassland, *Distichlis* meadows and degraded vernal wetlands: primarily *L. multiflorum, H hordeaceous.*

Moist annual exotic grasslands, *Distichlis* meadows, Le*ymus* meadows and vernal pool complexes in abandoned floodbasin depressions.Vernal pools:primarily *Downingia pulchella, Lasthenia conjugens, Psilocarphus brevissimus, Plagoibothrys stipitatus, Navarettia prostratum, Frankenia*

Larger vernal pool basins

Lactuca, Carduus thickets on stream levee crest

5 — Saline upland erosional basins, runoff slopes, salt scalds and saline/alkaline vernal pools on abandoned sream levee slope: Sparce cover of *Sueda moquinii* and *Hemizonia pungens.*

6 — Moist ruderal and exotic grassland: primarily *L.multiflorum, Hordeum depressum,Medicago polymorpha, Meliotus indica,* and *Geranium dissectum.*

LOWER FLOODPLAIN

7 — Lower salinity transition zone in abandoned floodbasins: primarily *Lolium multiflorum, Hordeum depressum Frankenia salina, Cotula coronopifolia, Salicornia subterminalis, Plagiobothrys stipitatus.*

8 — Higher salinity transition zone in abandoned floodbasins: primarily *Juncus bufonius, Cotulacoronopifolia, Hordeum depressum, Salicornia subterminalis.* Small pickeweed swales scattered thoughout

9 — Seasonally flooded pickleweed swales in abandoned floodbasins: primarily *Salicornia virginica*, *Coltula coronopifolia. Lasthenia conjugens* and *Plagiobothrys stipitatus* in more subsaline microhabitats.

10 — Saline, unvegetated drainage slopes, seasonally flooded saline swales, and salt flats in abandoned floodbasins.

11 — Irregularly flooded saline tidal pool and mudflat in abandoned floodbasins.

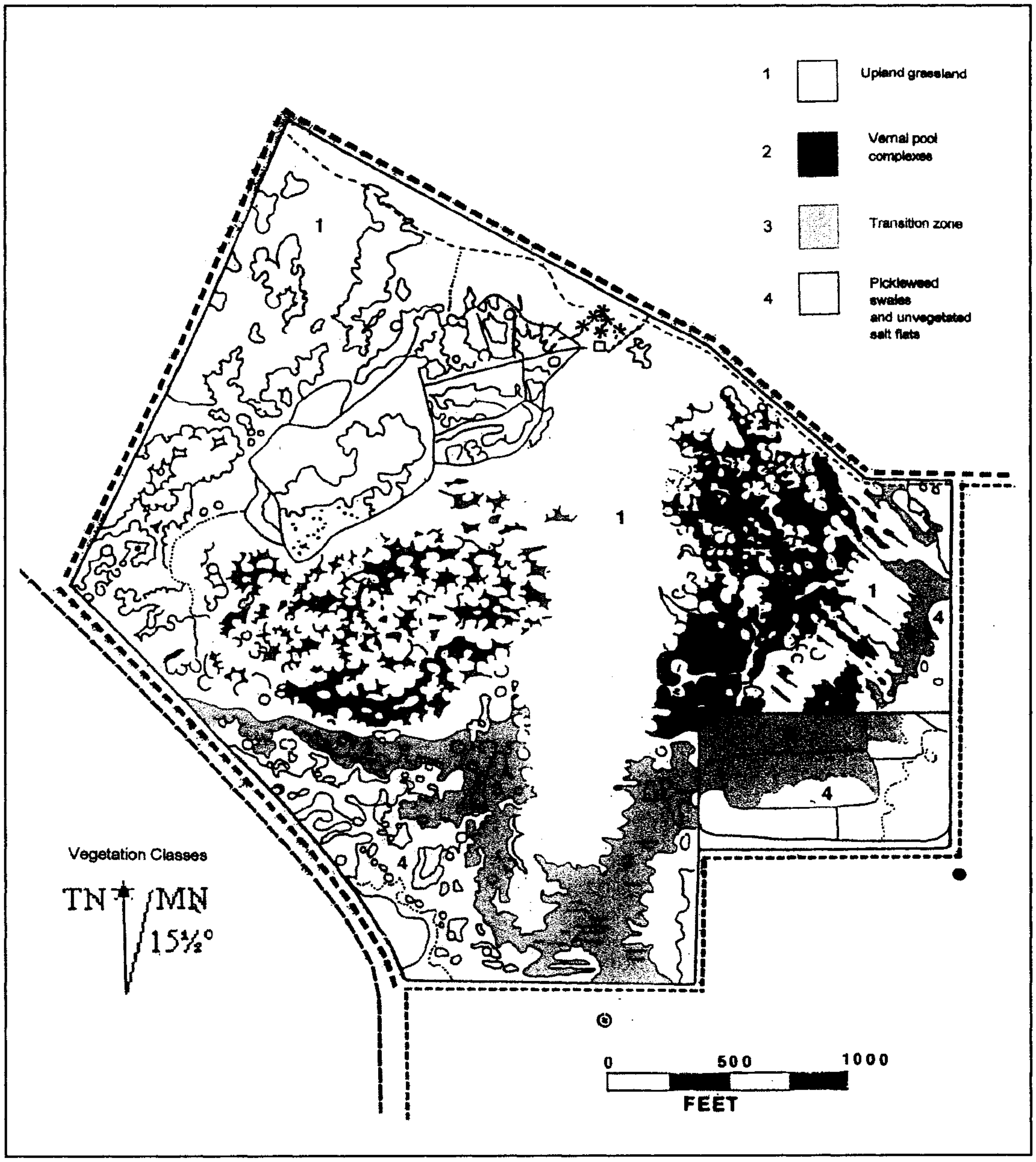


Figure 11. Vegetation zonation of the Warm Springs Seasonal Wetland, May 1998. White and green: grassland and vernal pool complexes, Red: transition zones, yellow: pickleweed swales, salt flats and hypersaline swales.

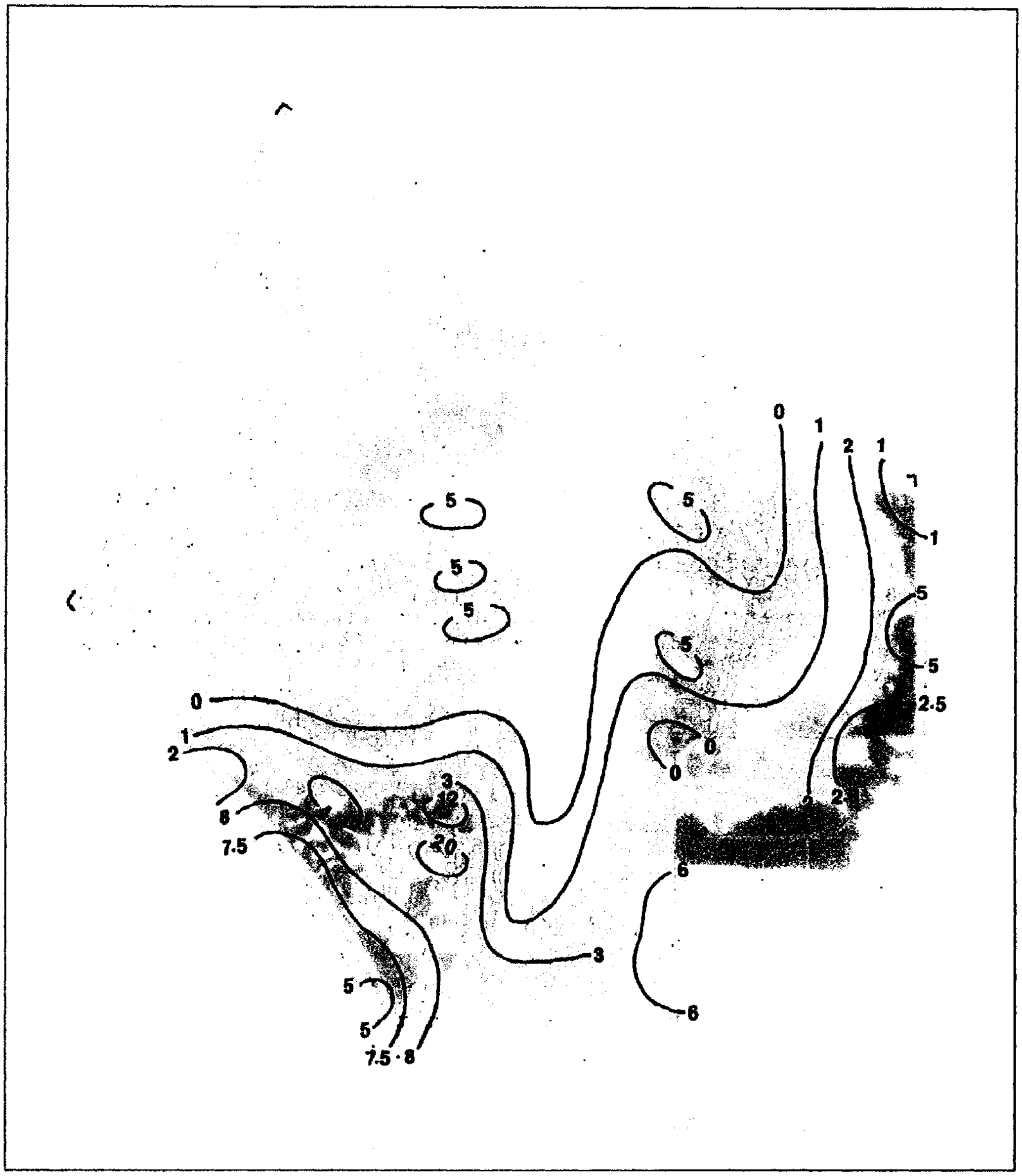


Figure 12. Apparent summer surface soil salinity (ppt) in the Warm Springs Seasonal Wetland, June 2000.

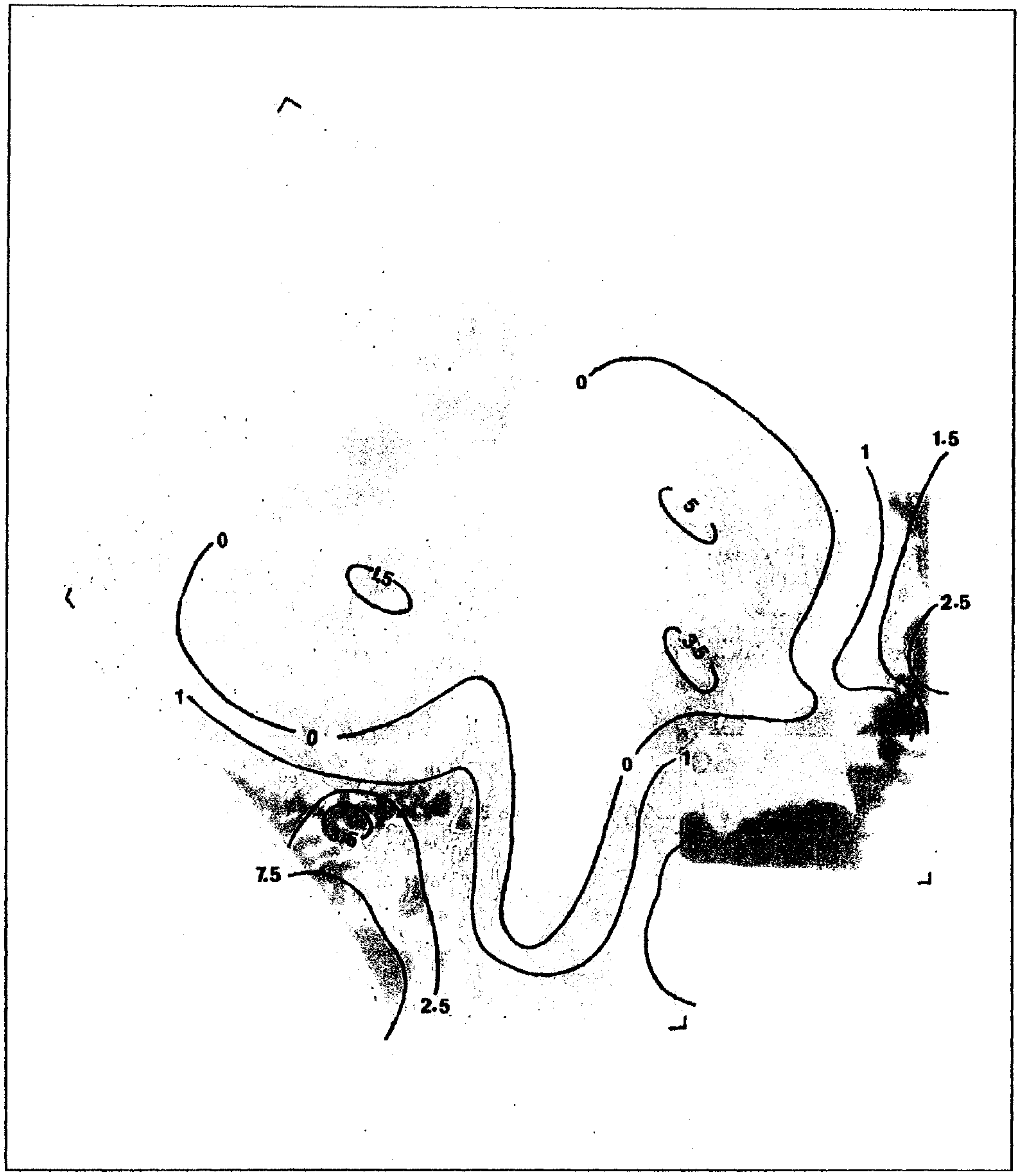


Figure 13. Apparent winter surface soil salinity (ppt) in the Warm Springs Seasonal Wetland, February 2001.

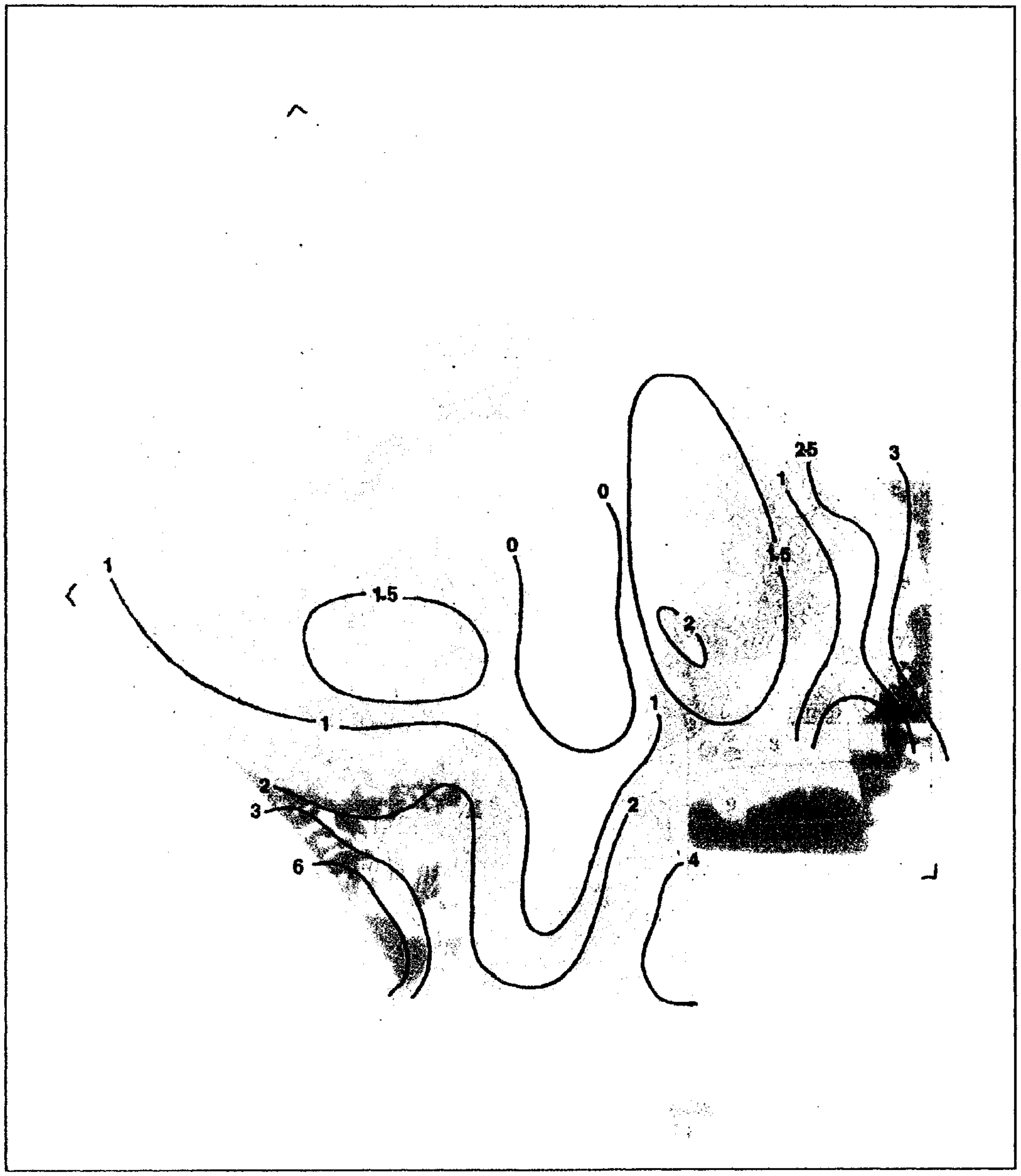


Figure 14. Apparent winter subsoil salinity (ppt) at one meter of depth in the Warm Springs Seasonal Wetland, February 2001.

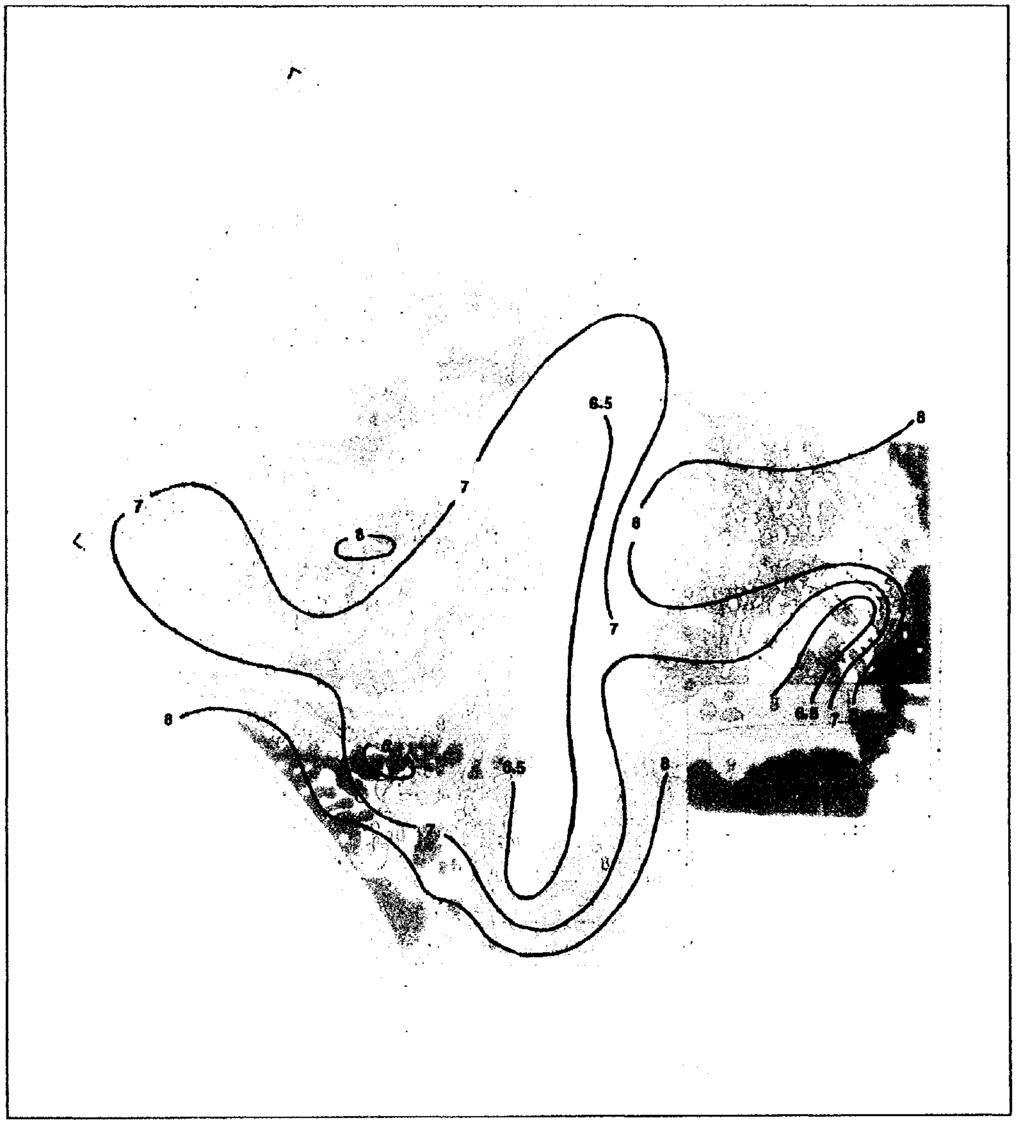


Figure 15. Winter surface soil pH in the Warm Springs Seasonal Wetland, February 2001.

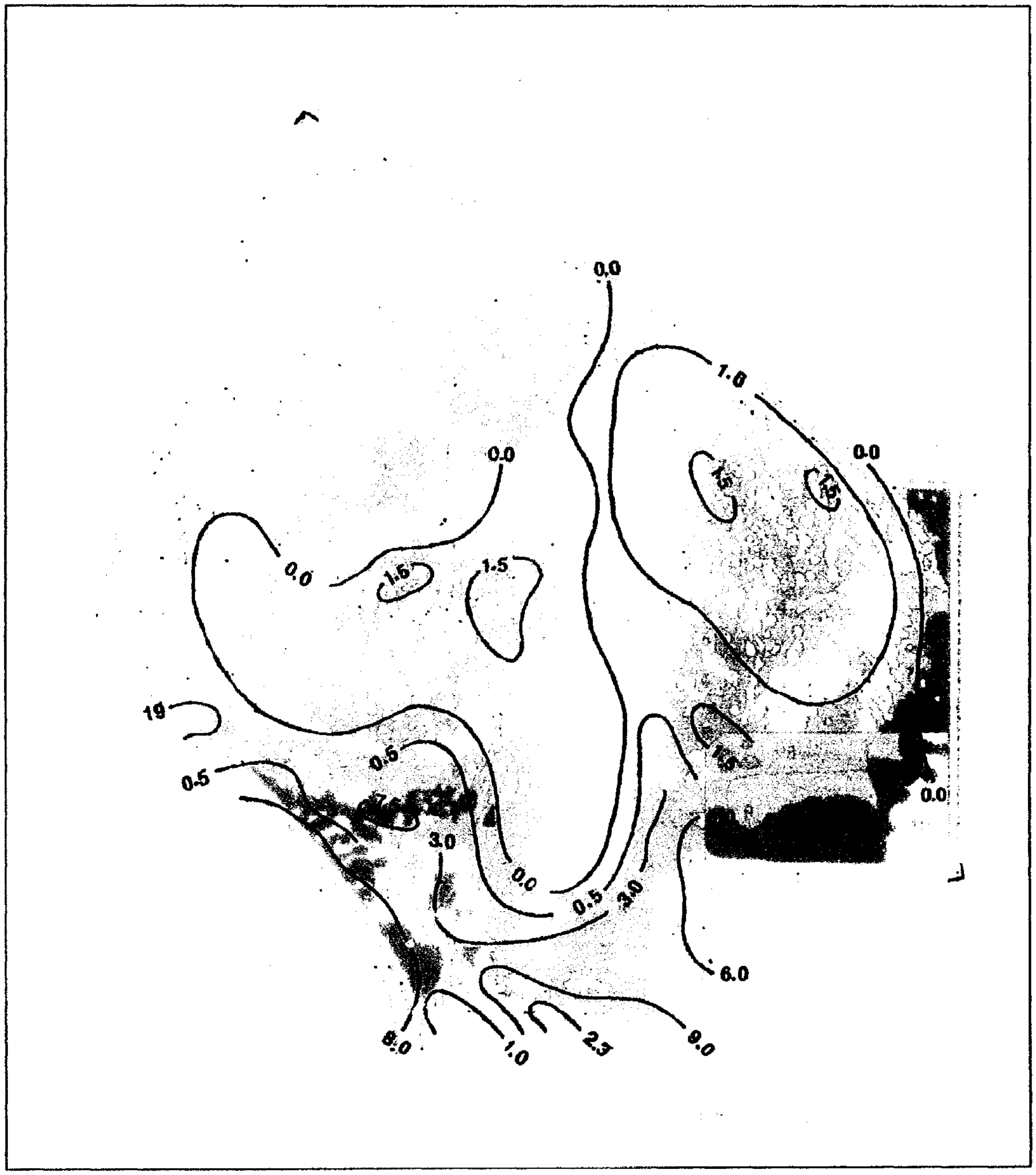


Figure 16. Standing winter floodwater salinity **(ppt) in the** Warm Springs Seasonal Wetland, February 2000.

THE DETERMINATION OF ENVIRONMENTAL FACTORS FROM PCA

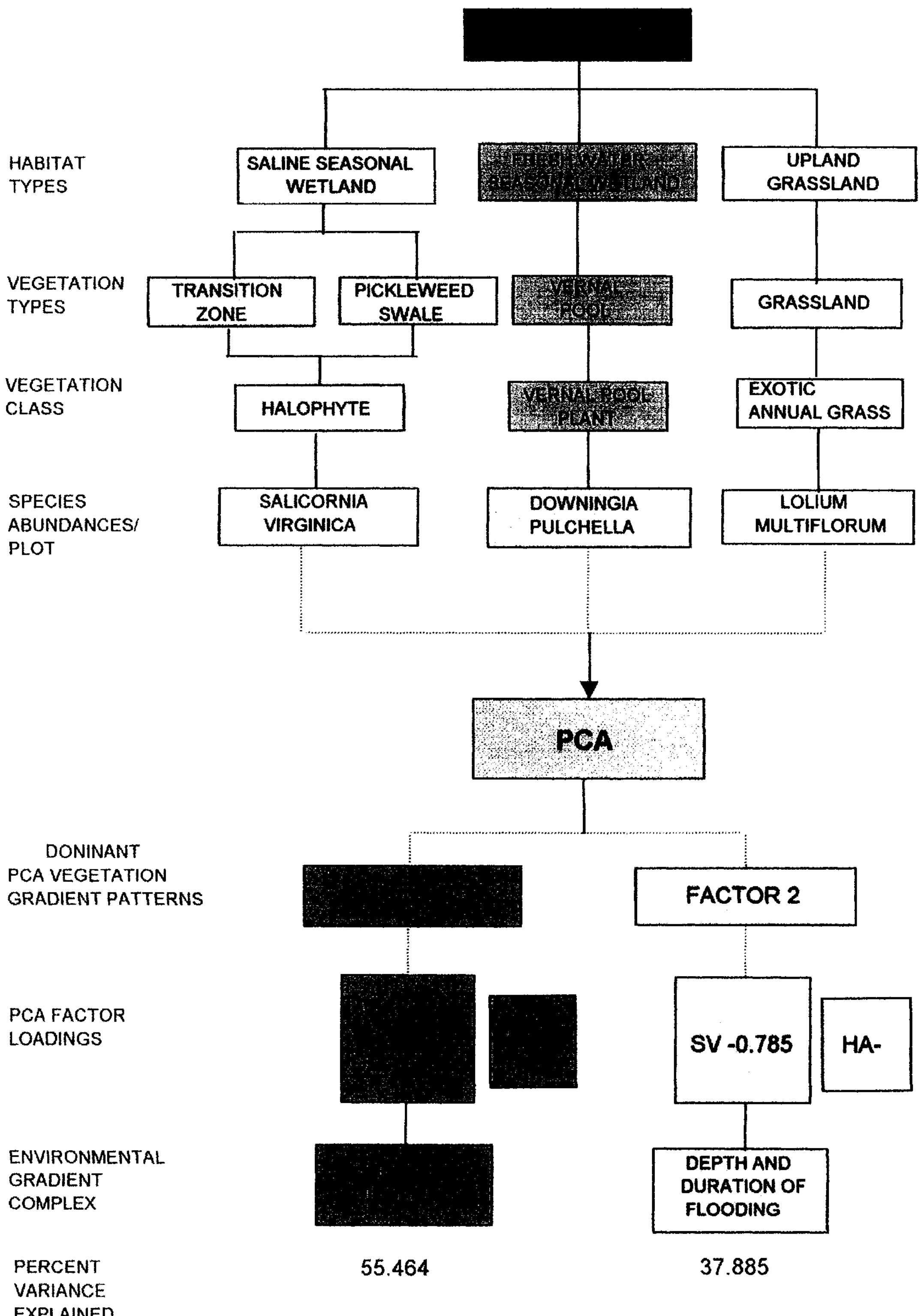


Figure 17. Determination of environmental factors from PCA factor loadings, *Plagiobothrys* model.

THE DETERMINATION OF ENVIRONMENTAL FACTORS FROM PCA

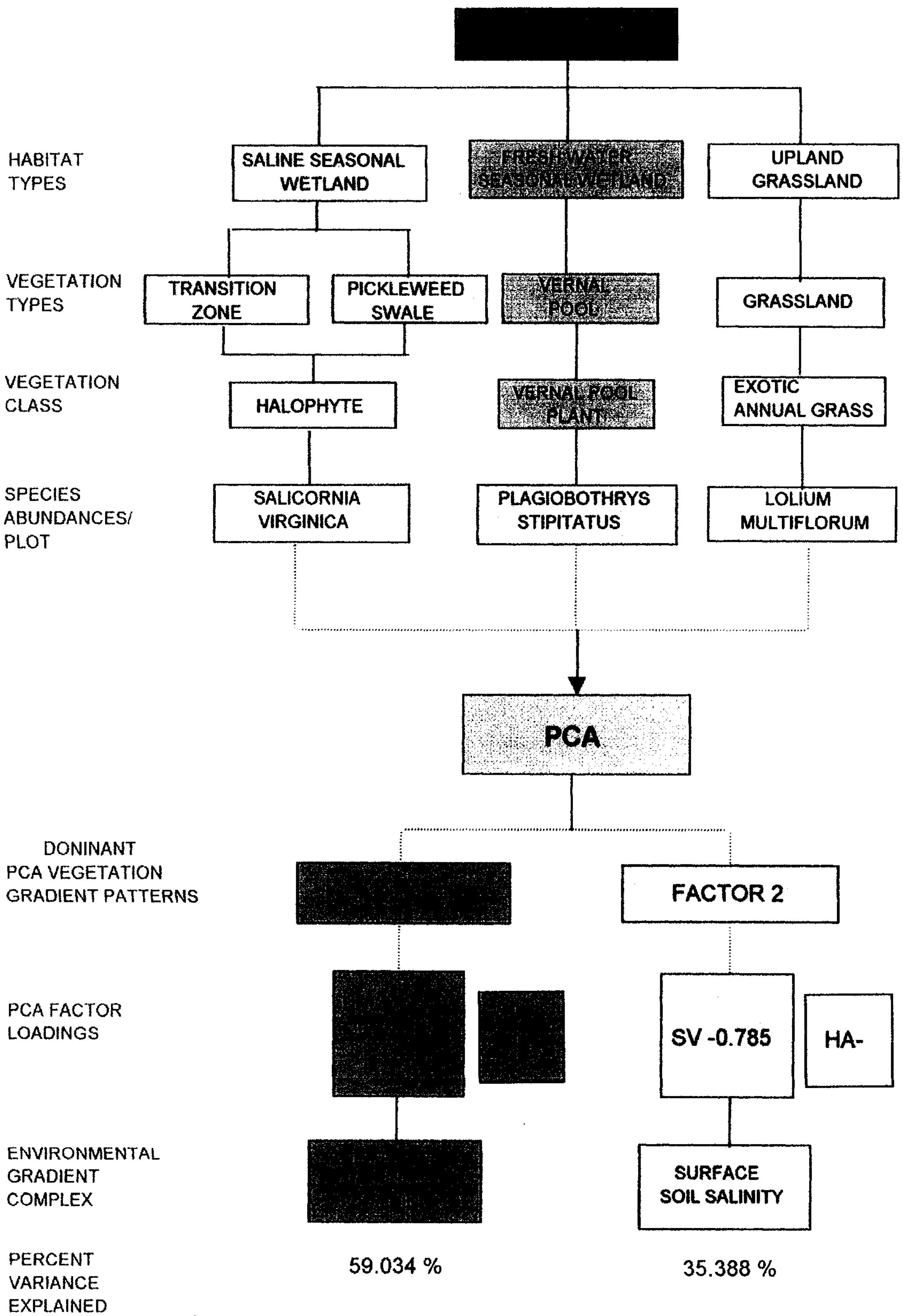


Figure 18. Determination of environmental factors from PCA factor loadings, *Downingia* model.

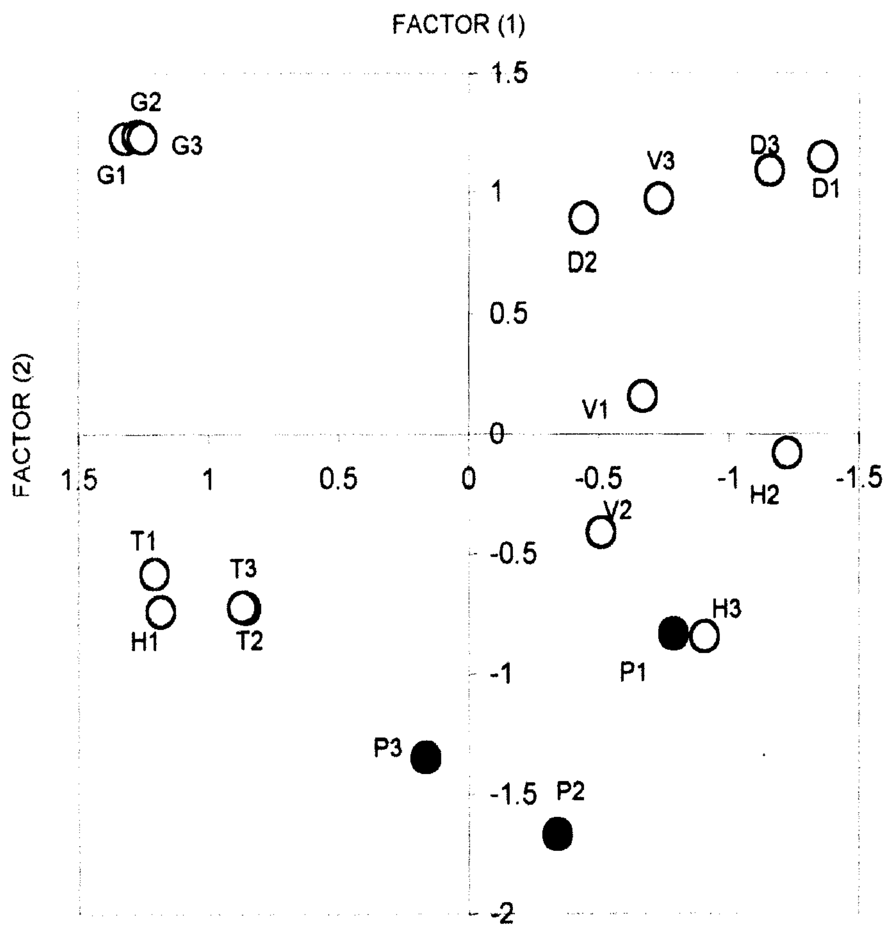


Figure 19.. PCA: *Lolium, Salicornia, Plagiobothrys* model. Scatterplot of factor 1 (flooding) verses factor 2 (surface soil salinity). Site codes of vegetation types, G: grassland, V: vernal pool, D: duck pond, H: lower salinity transition zone, T: higher salinity transition zone, P: pickleweed swale.

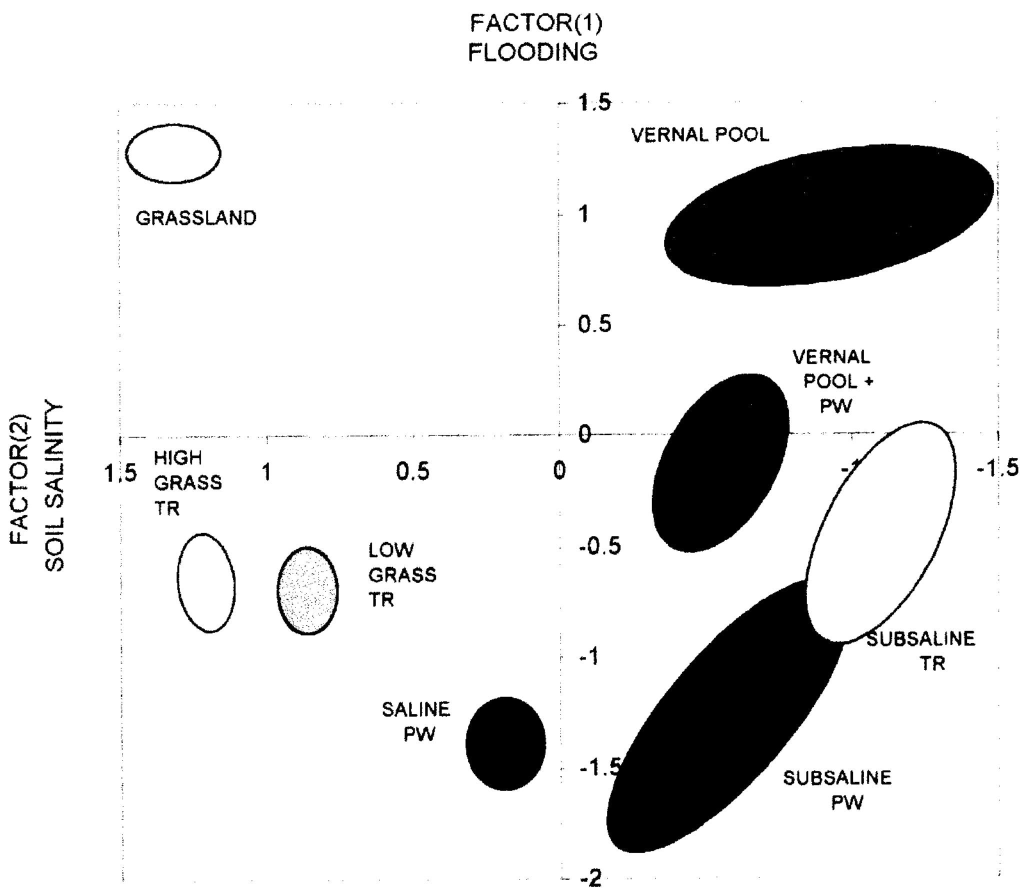


Figure20. Scatterplot of vegetation gradient from figure 25A

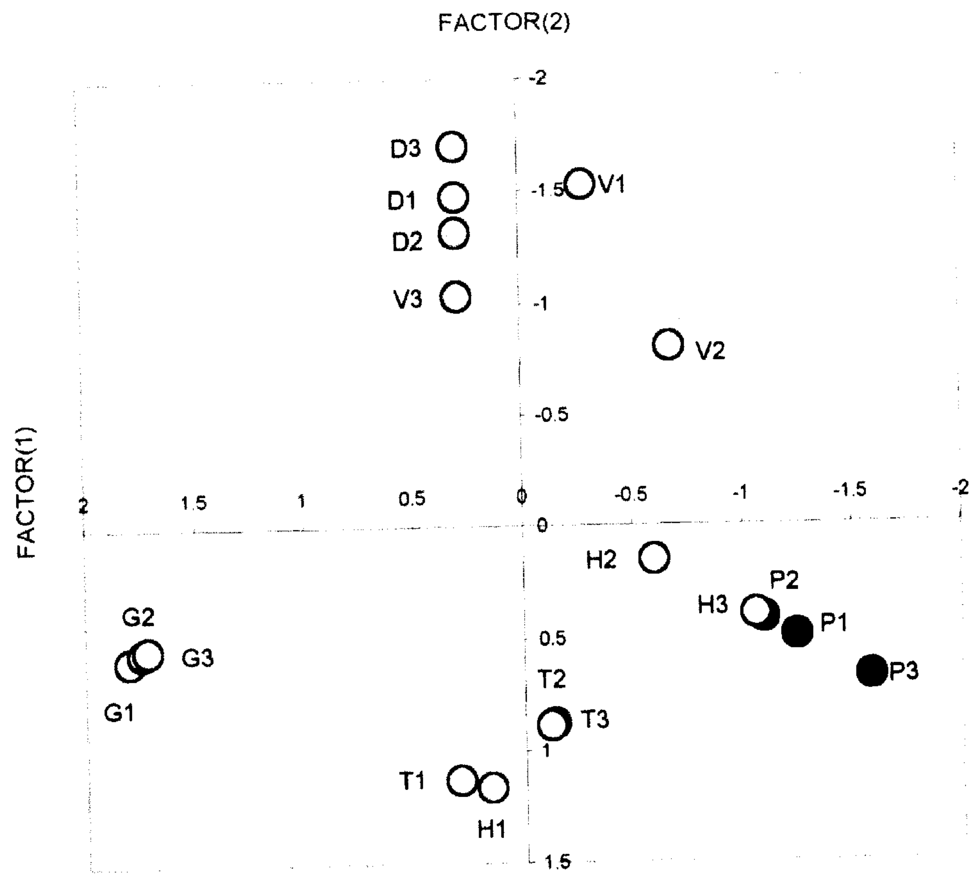


Figure 21. PCA: *Lolium, Salicornia, Downingia* model. Scatterplot of factor 1 (surface soil salinity) verses factor 2 (flooding). Site codes of vegetation types: G: grassland, V: vernal pools, D: duck pond, H: lower salinity transition Zone, T: higher salinity transition zone, P: pickleweed swale.

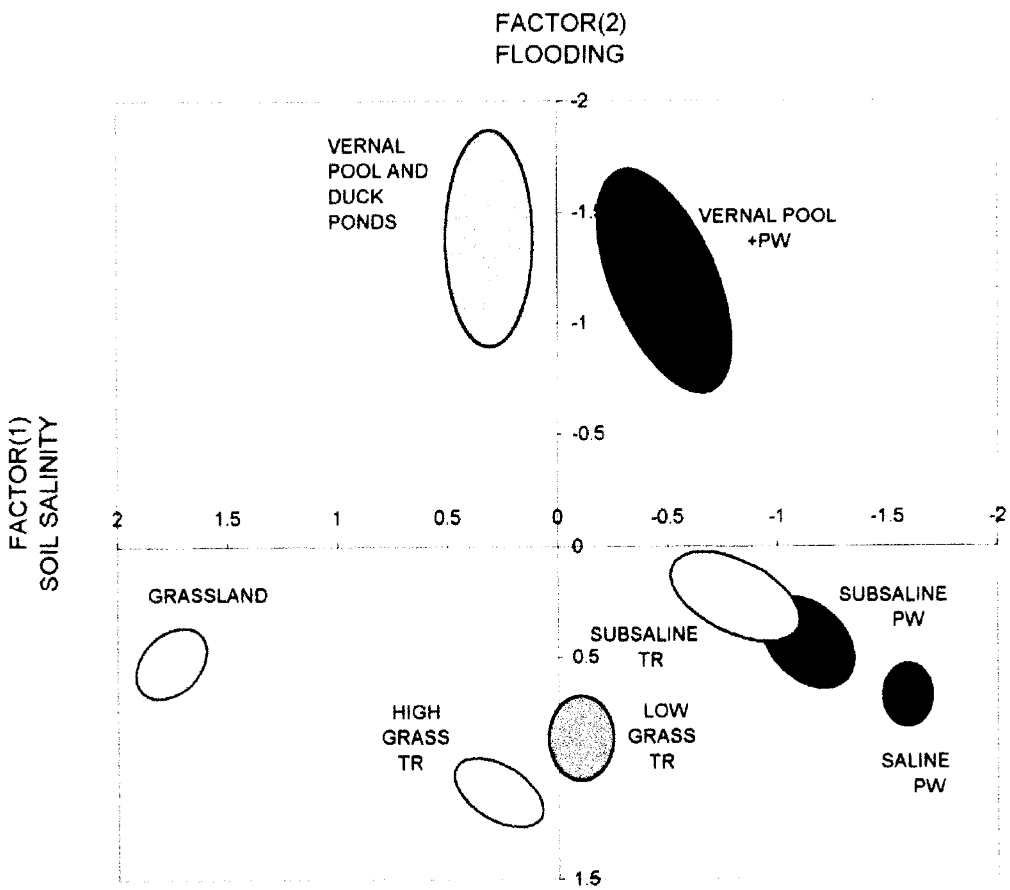


Figure 22. Scatterplot of vegetation gradient from figure 26A.

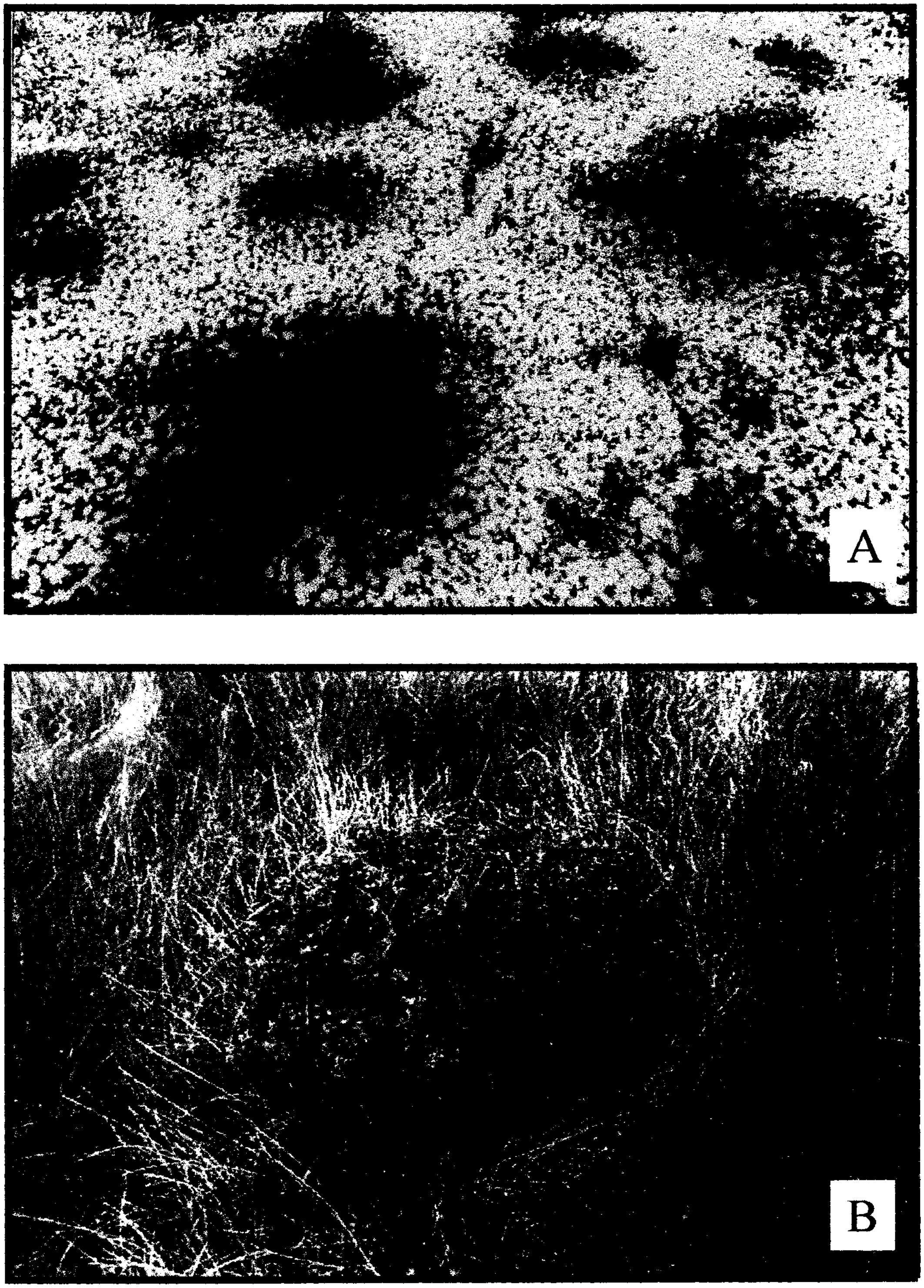


Figure 23. Mixed glycophyte and halophyte floras in the upper Warm Springs floodbasin in non-saline surface soils. A: *Lasthenia cojugens* and *Frankenia salina* in a vernal pool, B: *Lolium multiflorum* and *Fankenia salina* in grassland.

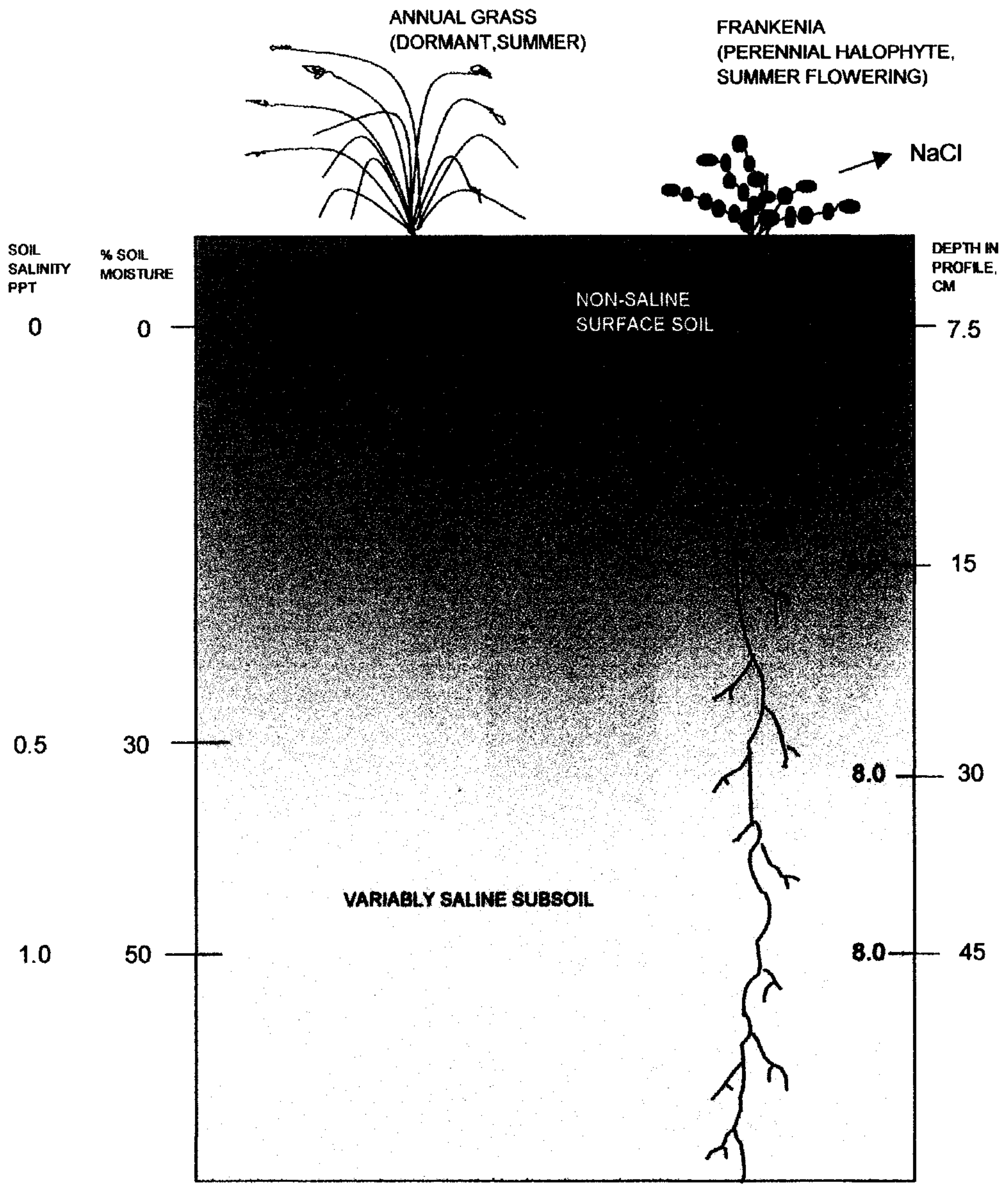


Figure 24. General salt-stratified soil profile in an upland grassland in the Warm Springs Seasonal Wetland, August 2000.

WARM SPRINGS SEASONAL WETLAND VEGETATION GRADIENT PATTERN

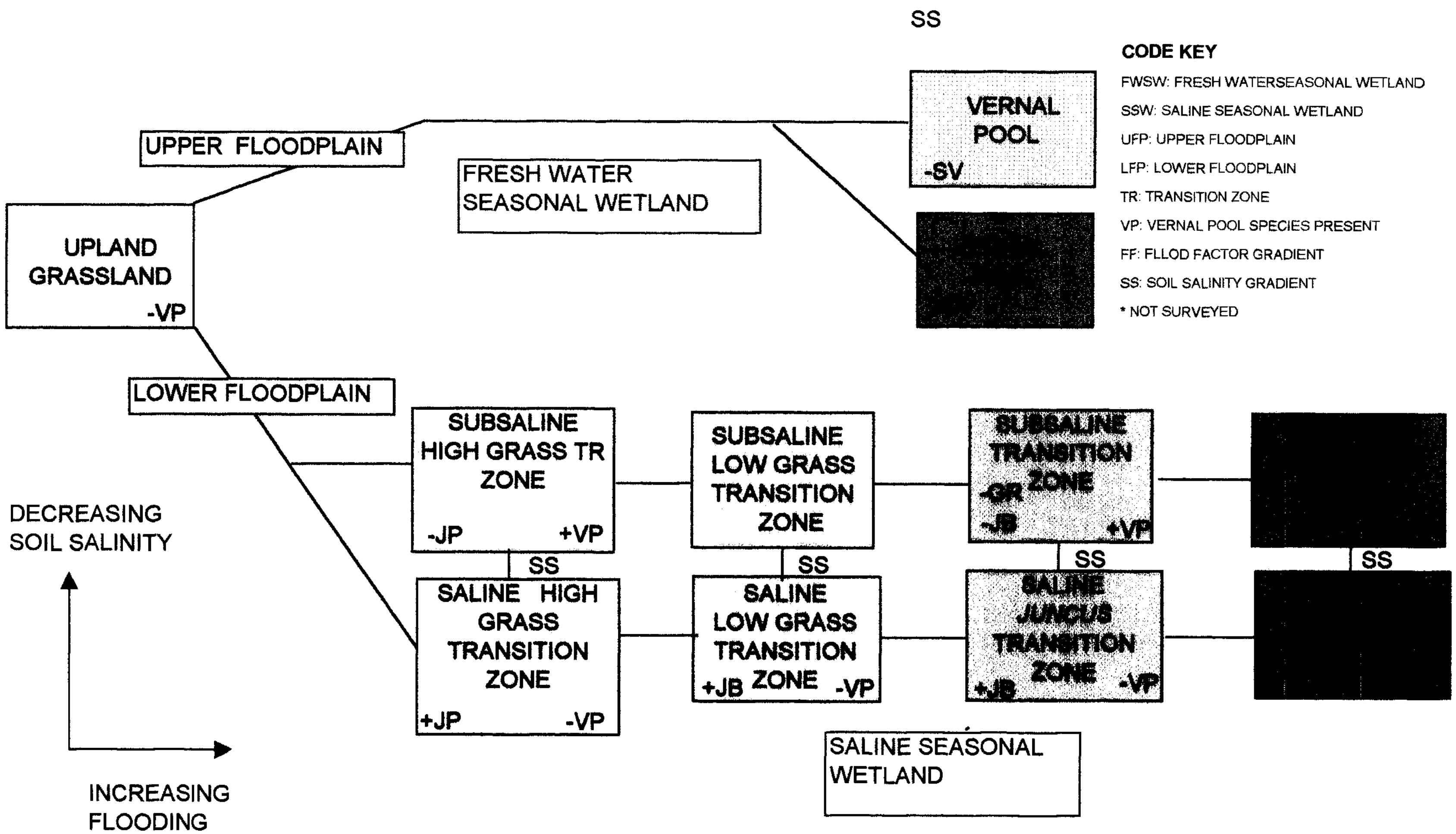


Figure 25. Vegetation gradients derived from PCA analysis of the Warm Springs Seasonal Wetland flora, May 1998.

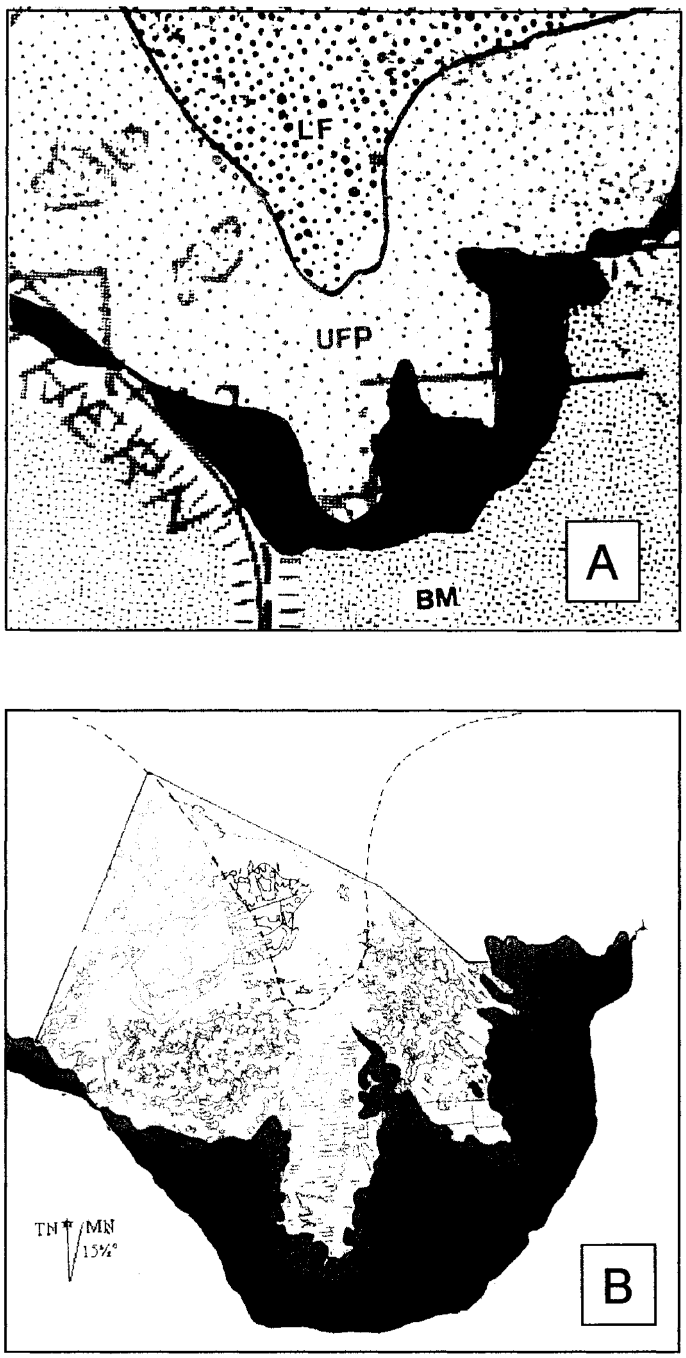


Figure 26. A: Distribution of alluvial soils on the Warm Springs floodplain. BM: Bay Mud, BR: saline basin rim, UFP: non-saline upper floodplain, LF: lower alluvial fan. B: hypothetical reconstruction of the historical floodplain showing vegetation zones. Color code: yellow: upper floodplain grassland and vernal pool complexex, red: saline transition zone, blue: pickleweed swales and saline runoff slopes.

Appendix I. Plant species list for six relict seasonal wetland sites around southern San Francisco Bay in 1996.

SPECIES	N/I	WS	DD	YB	LE	CH	C3
FLORA							
Eleocharis macrostachya	N	X	X	X	X	X	X
Frankenia salina	I	X	X	X	X	X	X
Rumex crispus	I	X	X	X	X	X	X
Polypogon monspeliensis	I	X	X	X	X	X	X
Lythrum hyssopifolia	I	X	X	X	X	X	X
Lythrum tribracteatum	I	X	X	X	X	X	
Cotula coronopifolia	I	X	X	X	X	X	
Distichlis spicata	N	X	X	X	X	X	
Salicornia virginica	N	X		X	X		
Downingia pulchella	N	X	X	X	X	X	
Bassia hyssopifolia	I	X	X	X	X		
Hemizonia pungens	N	X	X	X			
Lolium multiflorum	I	X	X	X			
Limocella acaulis	N	X	X	X			
Malvella leprosa	I	X	X	X			
Pleuropogon californicus	I	X	X				
Deschampia danthonoides	I	X	X				
Plagiobothrys stipitatus	N	X					
Sueda moquinii	N	X					
Crassula erecta	N	X					
Eletine brachysperma	N	X					
Lasthenia congjugens	N	X					
Lasthenia glaberrima	N	X				X	
Cressa truxullensis	I	X					
Atrilpex depressa	N	X					
Salicornia subterminalis	I	X					
Juncus bufonius	N	X					
Psilocarpus brevissimus	N	X					
Myosirus minimus	N	X					
Myosorus sessilis	N	X					
Castilleja ambigua	N	X					
Callitriche heterophylla	N	X					
FAUNA							
Limnaea sp.		X	X	X	X	X	X
Hyla rigella		X	X	X	X	X	X
Brachynecta lindhalli		X	X	X	X		X
Ambystoma californiense		X					
Lepidurus packhardii		X					

Site codes: WS; Warm Springs site, Fremont,DD Disk drive site, Alviso,Los Esteros/Arzinos Ranch site,Alviso,YB;Yerba Buena Rd.site,San Jose, CH; Coyote Hills site,Newark, C3; 3Com campus site, Jan Jose.
N/I native or introduced.

Appendix 2. Plant species list of the Warm Springs Seasonal Wetland,1998-2004

			Vegetation Type						
SPECIES	**COMMON NAME**	**N/I**	**GR**	**VP**	**DP**	**TR**	**PW**	**AP**	**A/P**
Apiaceae									
Eryngium aristatum	Button Celery	N		X					A
Foeniculum vulgare	Sweet Fennel	I	X						P
Lomatium caulifolium	Caraway Leaf Lomatium		X						
Lomatium utriculatum	Spring Gold	N	X						
Asteriaceae									
Anaphyalis margaritacea	Pearly Everlasting	I	X						
Baccharis pilularis	Coyote Bush	N	X						S
Carduus pycnocephalus	Italian Thistle	I	X						
Centaria solstitalis	Yellow Star Thistle	I	X						
Circium vulgare	Bull (Purple) Thistle	I	X						
Conyza canadensis	Horseweed	I	X						
Cotula australis	Southern Brass Buttons	I				X	X		A
Cotula coronopifolia	Brass Buttons	I		X	X	X	X		A
Hemizonia pungens	Tarweed	N	X					X	
Lactuca serricola	Prickly Lettuce	I	X						
Lasthenia conjugens ***	Contra Costa Goldfields	N		X	X	X	X		
Lasthenia gglaberrima	Glaberous Goldfields	N	X	X	X				A
Lasthenia glabrata	Smooth Goldfields	N	X						
Picris echinoides	Bristly Ox-Tongue	I	X						
Psilocarphus brevissimus	Wooly Marbles	N		X	X				A
Senecio vulgaris	Common Groundsel		X						
Sonchus asper ssp. Asper	Prickly Sow Thistle	I	X						
Sonchus olereus	Common Sow Thistle	I	X						
Sylibum marianum	Milk Thistle	I	X						
Aiozoaceae									
Mesembryanthemum crystallinum		I				X			
Boraginaceae									
Amsinckia mertensii	Rancher's Fireweed	I	X						
Galium trifolium	Bedstraw		X						
Plagiobothrys stipitatus	Popcorn Flower	N		X	X	X	X		
Heliotropium curassavicum	Salt Marsh Heliotrope			X	X				
Brassicaseae									A
Brassica nigra	Black Mustard	I							
Capsella bursa-pastoris	Shepherd's Purse	I	X						
Lepidium latifolia	Marsh Peppergrass	I	X		X	X			
Lepidium oxycarpum	Sharp-pod Peppergrass	N	X						
Raphinus sativus	Wild Radish	I	X						
Caryoplhillaceae									
Cerastum arvense	Field Chickweed	N	X						
Cerastum glomeratum	Sticky Mouse Ears		X						
Spergularia macrothecea	Sand Spurry	N				X	X		
Spergularia marina	Salt Marsh Sand Spurry	N				X	X		
Stellaria media	Common Chickweed	I	X						

SPECIES	COMMON NAME	N/I	GR	VP	DP	TR	PW	AP	A/P
Callitrichaceae									
Callitrische marginata	Califomia Waterwort	N		X	X				
Campanulaceae									
Downingia pulchella	Flat-Faced Calico Flower	N		X	X				
Chenopodiaceae									A
Atriplex leucophylla	Beach Saltbush	I		X					
*Atriple depressa**	Brittlescale	N		X		X			A
Salicornia europae	Annual Pickleweed	II				X			A
Salicornia subterminalis	Mexican Pickleweed	I				X			A
Salicornia virginica	Perennial Pickleweed	N					X		P
Sueda moquinii	Bush Seepweed	N						X	P
Bassia hyssopifolia				X	X				A
Convolvulaceae									
Cressa truxullensis	Alkali Weed	I		X	X	X			A
Cuscata salina	Marsh Dodder	N					X		A
Convolvulus arvensis	Field Bindweed	I	X						P
Crassulaceae									
Crassula aquatica	Pygmyweed	N		X	X				A
Crassula coronata	Sand pygmyweed	N		X					A
Crassula erecta	Erect Pygmyweed	N		X	X				A
Cyperiaceae									
Eleocharis macrostachya	Common Spike-rush	N		X	X				P
Eletinaceae									
Eletine brachysperma		N		X	X				A
Fabaceae									
Genista monospessula	French Broom	I	X						
Medicago polymorpha	Bur Clover	I			X				A
Melotus indicus	yellow sweet Clover	I			X				A
Trifolium microcephalum	Small Head Clover			X	X				A
Trifolium amplecans	Cow Clover	I	X						A
Trifolium varigatum	White-tipped Clover	N	X						A
Vica sativa	Spring Vetch	N?	X						A
Frankenaceae									
Frankenia salina	Alkali Heath	I	X	X	X	X			SS

SPECIES	COMMON NAME	N/I	GR	VP	DP	TR	PW	AP	A/P
Geraniaceae									
Erodium circutarium	Filaree	I	X						A
Geranium dissectum	Cut-leaf Geranium	I	X						A
Erodium moschaum	Whitestem filaree	I	X						A
Hydrophyllaceae									
Phacelia cillata	Field Phacelia		X						A
Juncaceae									
Juncus balticus	Baltic Rush	N		X	X				A
Juncus bufonius	Toad Rush	N				X			P
Juncus kellogii	Kellog's Rush	N			X				
Lilaea scilloides	Flowering Quillwort	N		X					A
Liliaceae									
Brodiaea coronata	Haevest Brodiaea	N	X						
Brodiaea terrstris	Dwarf Brodiaea	N	X						
Chlorogalum pomeridiarum	Soap Plant	N	X						
Mullia maritima	Common Mullia	N	X						
Lamiaceae									
Lamium plexicaule	Red Henbit		X						A
Lythraceae		N	X						
Lythrum hyssopifolia	Loosestrife	I		X	X				A
Lythrum tribracteatum	Three-bract Loosestrife	I		X	X				A
Malvaceae									
Malvella leprosa	Alkali Mallow	I		X	X				A
Malvella neglecta	Common Mallow	I	X						
Oxalidaceae									
Oxalis pes-caprae	Sourgrass	I	X						A
Onegraceae									
Camissonia ovata	Sun Cups	N	X						A
Epilobium bracyspermum	Willow Herb		X						
Papaveraceae									
Eschscholzia californica	California Poppy	N	X						
									P
Plantaginaceae									
Plantago elongata	Linear-leaf Plantain	N	X						A
Plantago erecta	Erect Plantain	N		X					A
			X						

SPECIES	COMMON NAME	N/I	GR	VP	DP	TR	PW	AP	A/P
Poaceae									
Avena barbata	Slender Wild Oats	I	X						A
Bromus diandrus	Ripgut Brome	I	X						A
Bromus hordeaceus	Soft Cheat Grass	I	X						A
Puccinella simplex	Alkali grass	N		X	X				
Deschampia danthonoides			X						A
Distichlis spicata	Saltgrass	N	X						P
Hordium murinum ssp. Leporinum	Hare Barley (Foxtail)	I	X						A
Hordium murinum ssp.gussorean	Mediterranean Barley	I	X						A
Leymus triticoides	Creeping Wild Rye	N	X			X			P
Lolium multiflorum	Italian Ryegrass	I	X			X			A
Nassela pulchra	Purple Needle Grass	N	X						
Poa annua	Annual Blue Grass	I	X						A
Phaleris aquatica	Harding Grass	I	X						
Pleuropogon californicus	Semiphore Grass	N	X	X	X				A
Polypogon monspeliensis	Rabbit Foot Grass	I		X	X				A
Puccinellia simplex	Cailf. Alkali Grass	N	X						A
Vulpia bromoides	Brome Fescue	I	X						A
Vulpia myros	Fescue	I							A
Polemonaceae									
Navarretia prostratum		N		X	X				A
Polygonaceae									
Rumex crispus	Curly Dock	I		X	X				
Primulaceae									
Anagallis arvensis	Sacrlet Pimpernel	I	X						A
Ranunculaceae									
Ranunculus californicus	California Buttercup	N	X			X			
Myosirus minimus	Little Mousetail	N		X	X		X		A
Myosorus sessilis	Sessile Mousetail	N		X				X	A
Ruppiaceae									
Ruppia maritima	Ditch Grass	I					X		A
Scrophulariaceae									
Castilleja ambigua	Salt Marsh Owl Clover	N	X			X			A
Limocella acaulis	Mudwort	N		X	X				
Zanichellaceae									
Zanichella palustris	Ditch Grass						X		A
Total Species			**72**	**39**	**37**	**21**	**12**	**4**	
Total native species			21	23	20	10	8	4	
Total exotic species			51	16	17	11	4	0	
% native species			29	59	54	47	66	100	

Algae of the Warm Springs Seasonal Wetland, 1998

SPECIES	**GR**	**VP**	**DP**	**TR**	**PW**	**AP**
Anabaena sp.		X			X	
Closterium sp		X			X	
Cosmarium sp.		X				
Cryptonema sp.		X			X	
Cylindrospermum sp.		X			X	
Euglena proxima		X				
Euglena viridis		X				
Monostroma sp.					X	
Micrococlus lacustris		X				
Nostoc commune		X				X
Oedegonium sp.		X				X
Oscillatoria sp.		X				
Tribonema utriculosum		X				
Vaucheria geminata		X	X	X		
Vaucheria sessilis		X	X			
Enteromorpha intestinalis					X	
Ulva angusta					X	
Ulva compressa					X	
Total Species		**14**	**2**	**1**	**8**	**2**

Vegetation Type: GR, VP, DP, TR, PW, AP

* CNPS inventory, list 1B
** Federally listed, endangered

GR grassland
DP duck pond
VP vernal pool
TR transition zone
PW pickleweed swale
AP alkaline vernal pool

N native
I introduced

A annual
P perennial
S shrub
SS subshrub